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THE RELATIONSHIP BETWEEN VEGETATION GROWTH AND AIRBORNE INDUSTRIAL GYPSUM DUST DEPOSITION

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WILLIAM CARL JAMESON

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THE RELATIONSHIP BETWEEN VEGETATION GROWTH AND AIRBORNE INDUSTRIAL GYPSUM DUST DEPOSITION

APPROVED BY

DISSERTATION COMMITTEE

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Many people contributed to the completion of this study and it would be impossible to thank them all. A special expression of appreciation is extended to all associated with the United States Gypsum Company processing plant at Southard, Oklahoma, and to all the residents of the Southard community who gave of their time and provided assistance in the research.

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Finally, to my wife Molly and my children Luke and Marylee, thank you for putting up with the entire experience.

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ABSTRACT

This study is concerned with the relationship between airborne industrial gypsum dust deposition in the environment and the growth rate of trees. The objective is to determine (1) the existence of a relationship, (2) the extent of the affected vegetation, and (3) any change in the extent of affected vegetation over a period of years as a result of increased gypsum production and/or installation of air pollution controls.

In order to determine the relationship, the study focuses on gypsum production, pedology, climatology, and topography as well as the growth rate of trees.

Randomly selected tree cores were utilized for the analysis of growth rate. A trend surface analysis was performed on five selected growth periods to show the relationship between inhibited growth and distance from the emission source of gypsum dust pollution.

Growth inhibition is attributed to a reduction in photosynthesis as a result of the heavy deposition of reflective gypsum dust on the leaf canopy. The accumulation of dust is interpreted as being a result of gypsum production, wind speed and direction, precipitation, and topography.

The difference in extent and degree of growth inhibition in each of the selected growth periods points to the effectiveness of the industrially installed air pollution controls.

THE RELATIONSHIP BETWEEN VEGETATION GROWTH AND AIRBORNE INDUSTRIAL GYPSUM DUST DEPOSITION

CHAPTER I

INTRODUCTION TO THE PROBLEM

Since the mid-1960's there has been an increasing emphasis on environmental awareness. Attention was then and is now focused on how human beings are altering their habitat, and the effect such alterations have on men and other life forms. In particular, a significant amount of research activity into the origin, transportation, deposition, and ultimate biological and ecological effects of different types of air pollution in the environment has been undertaken. This paper is concerned with the effects of one type of particulate air pollution on members of a natural climax forest community.

Air pollution is defined as:[1]

> The presence in the outdoor atmosphere of any form of contaminant . . . inimical or which may be inimical to the public health, safety, or welfare, or which is, or may be injurious to human, plant, or animal life, or to property, or which reasonably interferes with the comfortable enjoyment of life or property.

Particulate pollution is often referred to as dust,[2] and is

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[1]Wilfred Bach, Atmospheric Pollution (New York: McGraw-Hill Book Company, 1972), p. 4.

[2]Ellis F. Darley, "Studies on the Effect of Cement-Kiln Dust on Vegetation," Journal of the Air Pollution Control Association 16 (March 1966): 145

defined as fine, dry, pulverized particles of earth. The word dust is usually used to denote:[3]

> . . . soil from areas of denuded vegetation, whipped up by natural winds, or by the passage of vehicular traffic, or by agricultural activities. The particles are usually large, so that under most circumstances such dust will not travel great distances.

Thus defined, it is easily seen that a dust can be any one of many kinds of material found on and in the earth. Dust can originate naturally in the environment, or it can be generated by the activities of man, particularly by his industrial activities.

The geographic implications of dust in the atmosphere are significant in that this material can be carried aloft and dispersed by winds for great distances before coming to earth. Pollutants from a single source have been tracked across large parts of the United States.[4] Indeed, they have been distributed to nearly all parts of the globe.[5] It is estimated that every year in the United States over 12 million tons of dust are emitted into the environment from industry, automobiles, power plants, and refuse disposal.[6]

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[3] Air Conservation, Publication No. 80 of the American Association for the Advancement of Science, Washington, D.C. (1965), p. 31.

[4] F. P. Hall, Jr., and Richard R. Hagan, A Preliminary Case Study of Long Distance Transport of Air Pollution, Department of Meterology Special Publication, University of Oklahoma, Norman (1971), p. 2. This study concludes that suspended particulate air pollution was carried aloft over 500 miles from a source region centered in Ohio to an impact region in north Texas.

[5] Reginald E. Newell, "The Global Circulation of Atmospheric Pollutants," Scientific American 224 (February 1971): 32-42.

[6] The Sources of Air Pollution and Their Control, Public Health Service Publication No. 1548, U.S. Government Printing Office, Washington, D.C. (1969), pp. 3-13.

Statement of the Problem

Research emphasis has mostly been placed on toxic pollutants such as the nitrogen and sulfur oxides, with the result that little research has been conducted on the effects of non-toxic industrial dusts. A toxic pollutant involves a substance that can cause injury or death on being taken internally. A non-toxic pollutant may involve a substance that may have no detrimental effect when taken internally, or it may refer to a substance which makes depositional contact with a vegetation surface and has the potential to act as a reflectant to the incident solar radiation. Little is known of the response of natural biological communities or individual species to non-toxic pollution. Most air pollution literature has dealt with the effects on man, on species whose physiology is similar to man's, or to agricultural crops.[7]

This study is designed to investigate one type of non-toxic industrial dust and its effect on certain members of a natural biological community. Specifically, its purpose is to examine the relationship between industrial gypsum dust fallout and the growth rate of oak trees. The research premise is that gypsum dust falling on the trees in critical quantities is responsible for inhibiting their growth rate. Based on a pilot study, there may also exist the potential for the dust to accelerate the growth rate of trees depending on the amount of dust accumulation.[8] The response of the vegetation to the dust is considered to be a function of the concentration of the dust fallout which

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[7]David W. Ehrenfeld, Biological Conservation (New York: Holt, Rinehart, and Winston, Inc., 1970), p. 60.

[8]William Carl Jameson and Joseph B. Schiel, Jr., "A Preliminary Investigation on the Relationship between Gypsum Dust and Vegetation Growth," Bios 43 (1972): 65-69.

decreases with distance away from the emission source. The dual role of the dust is attributed to two processes. First, the dust falling on the vegetation in critical quantities can inhibit photosynthesis either by reflecting the light waves or by clogging the stomata in the leaves and thus inhibiting the normal exchange of gases. Second, it may be possible that the dust in lighter quantities can accelerate tree growth by functioning as a soil conditioner.[9] Since the accumulation of dust on vegetation is a function of the ability of the particles to remain airborne, the response of vegetation to gypsum dust fallout is related to distance and direction from the emission source as well as climatology.

Research Hypothesis

The main research hypothesis of this study is that there exists a curvilinear relationship between industrial gypsum dust fallout and the growth rate of vegetation. It is postulated that dust has an effect on vegetation, likely a detrimental effect, as a result of heavy concentrations of gypsum dust deposition.

Of primary concern is the direct effect of the dust fallout on the vegetation. Although certain site characteristics--vegetation density, biomass, soil characteristics, soil field capacity, topography, and climatology--may partially explain the effect, the predominant influence is hypothesized to be industrial gypsum dust fallout. The

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[9] Ibid., p. 67. Jameson and Schiel advance the proposition that the calcium in the gypsum dust ($CaSO_4$) falling on the ground is leached into the soil where it stimulates ion exchange and thus provides for a more vigorous plant growth. This would occur close to the emission source, but the reduced photosynthesis occurring there as a result of the heavier dustfall on the leaves would offset any potential advantage conferred as a result of the dust acting as a soil conditioner.

problem may be approached within the context of the following substantive hypothesis and supportive hypotheses.

Substantive Hypothesis: There is a curvilinear relationship between gypsum dust fallout and the growth rate of vegetation.

Supportive Hypothesis I: The growth rate response of vegetation exposed to industrial gypsum dust fallout is a function of the distance from the emission source of the dust.

Supportive Hypothesis II: Growth rate response of vegetation is a function of the amount of dust deposition on the vegetation.

Rationale

In order to appreciate the magnitude of the air pollution problem in the world today one need only look at the literature currently available in the many scientific journals and popular magazines. Great quantities of research effort and money are being expended on air pollution analysis, monitoring, and control, and every year there is an increase in the amount of pollution in the environment. Scientists are building an impressive bank of knowledge on air pollution, but the field is relatively young and contributions are needed. It is intended that this study make a contribution to this expanding information bank.

Industrial gypsum dust as a particulate pollution is somewhat unique because despite the great amount of scientific research on air pollution gypsum dust has gone virtually unnoticed. This is rather surprising in light of the large number of natural gypsum deposits and gypsum processing plants in the United States (Figure I-1). Perhaps more important, however, it may be unique from the standpoint that in

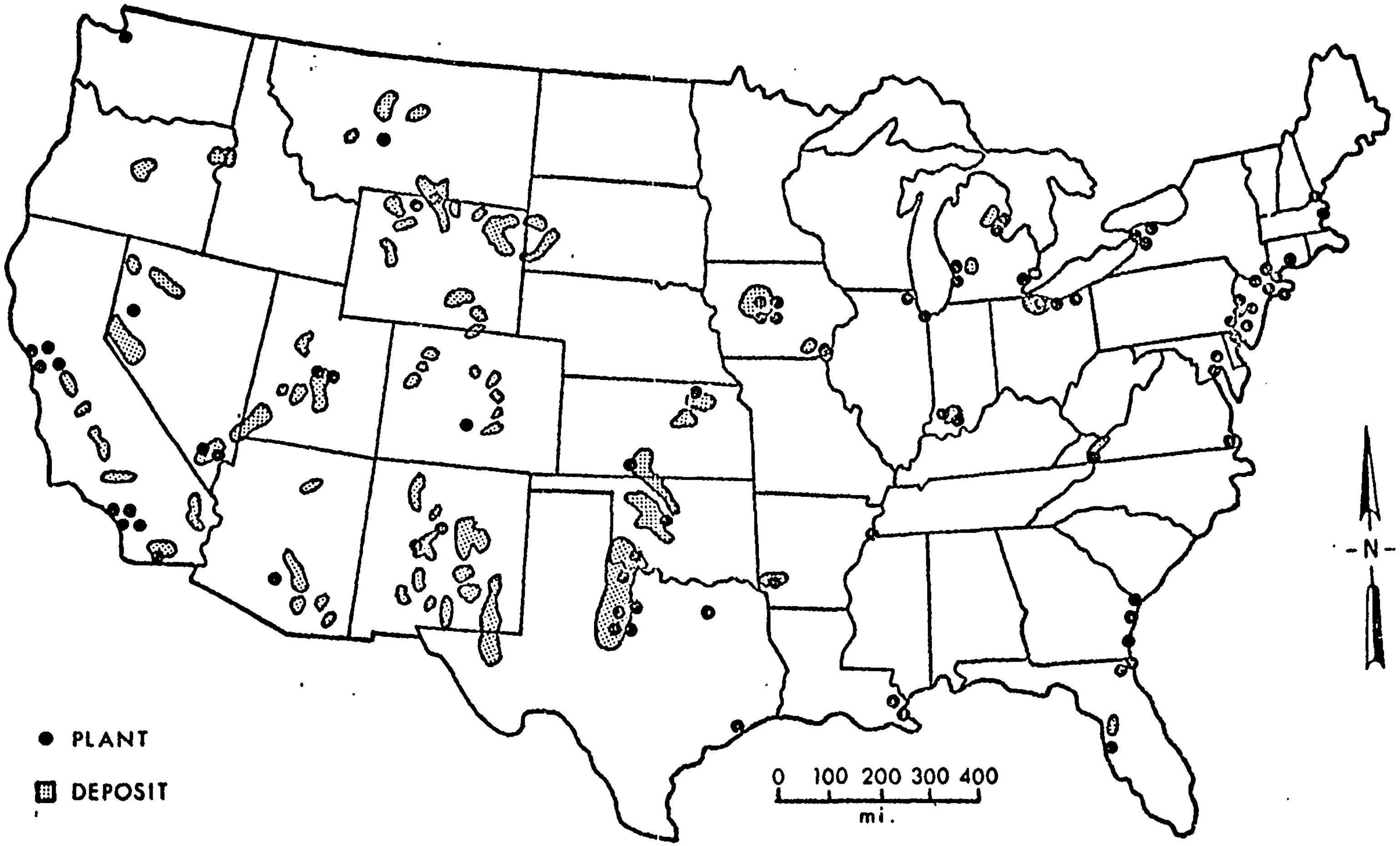

Figure I-1. Gypsum deposits and gypsum processing plants in the United States. (Source: The Gypsum Association.)

critical quantities it may possibly have a beneficial effect on vegetation. If the preliminary findings of Jameson and Schiel hold up under more sophisticated analysis, it would place gypsum dust in an extremely rare category--that of an air pollutant having a beneficial effect.

In addition to analyzing the direct effect of the dust on the vegetation, this study should also provide insight into the effectiveness of industrial air pollution controls. If, as expected, heavy dustfall is conducive to restricted vegetation growth, it follows that most growth inhibition will be observed in the immediate vicinity of the processing plant. If the dustfall in lighter quantities does indeed act as a soil conditioner, the trees exposed to these lighter quantities some further distance downwind from the processing plant may demonstrate an accelerated growth pattern. Still further downwind where the dustfall is considerably reduced or non-existent, growth rate should be normal. Graphically, a simplified theoretical relationship such as the one in Figure I-2 might exist. In order to assess the effectiveness of air pollution control devices, growth rates for trees for different time periods can be graphed to show the temporal changes in growth rate. If the controls have been effective in reducing the effluent, then a curvilinear relationship between growth rate and distance from the emission source for a recent period should show less growth rate inhibition than for an earlier time period, assuming controls were installed some time between the two time periods being investigated (Figure I-3). This relationship also assumes a certain constancy of climate.

If the controls are not functioning properly, and production at the plant has increased since the earlier time period, then a

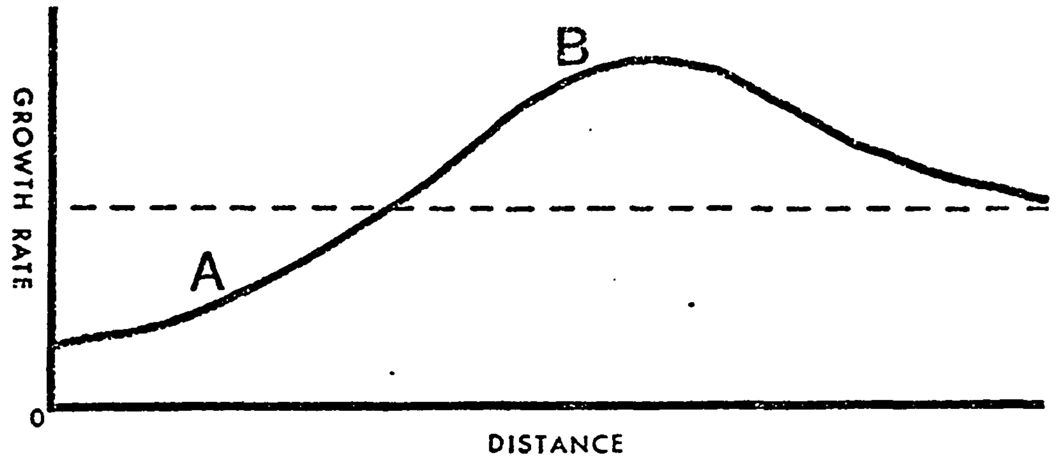

Figure I-2. Estimated relationship between the growth rate of vegetation and distance from the emission source of gypsum dust. Dashed line represents the normal growth rate condition. The part of the curve labeled A represents restricted growth; B represents accelerated growth.

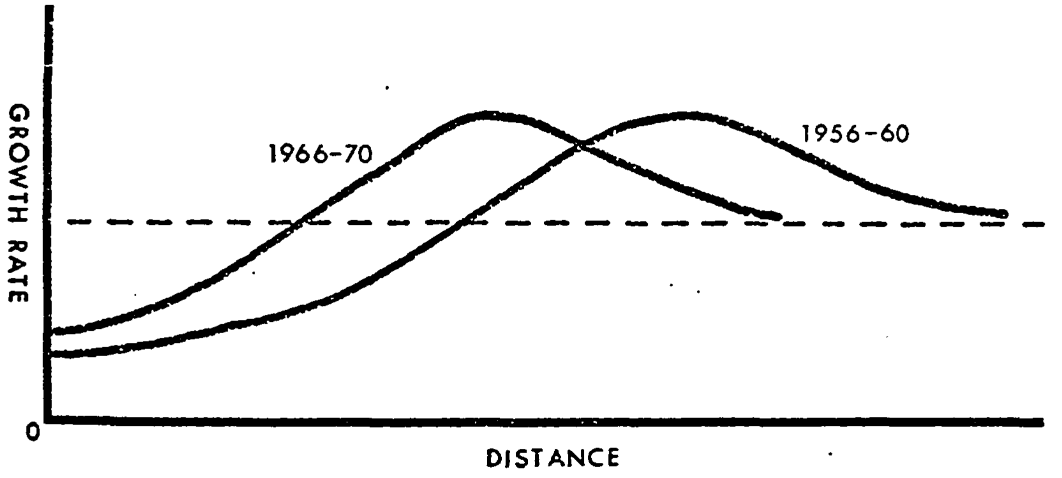

Figure I-3. Suspected difference in growth rate of vegetation for two different time periods. The 1966-70 curve represents the growth condition assuming a successful reduction in effluent as a result of effective air pollution controls. The 1956-60 curve represents the theoretical growth rate/distance relationship before the installation of the controls.

relationship such as the one depicted in Figure I-4 might occur, with the most recent time period showing more growth inhibition. This assumes, of course, that the environmental conditions for the two time periods are similar. In either case, the industry will get a clue as to the effectiveness of the controls they have installed.

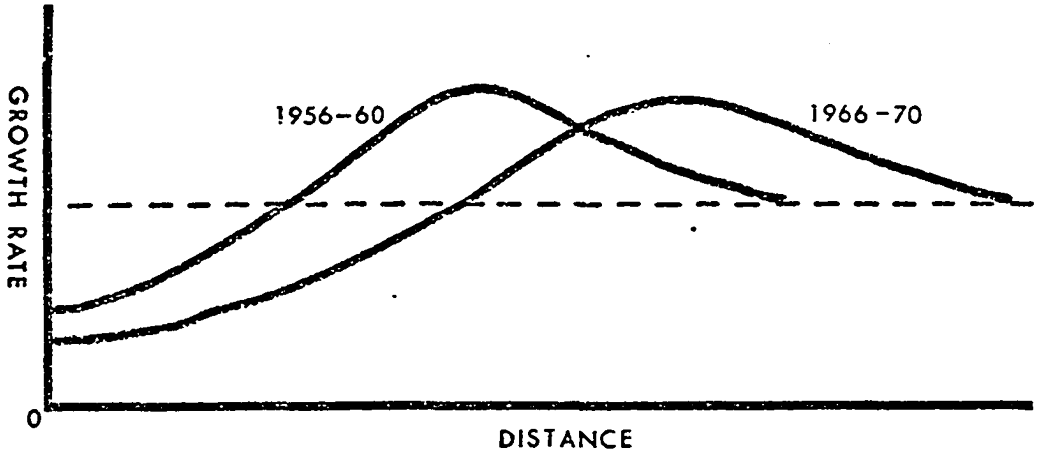

Figure I-4. Suspected difference in growth rate of vegetation for two different time periods assuming ineffective air pollution controls accompanied by an increase in gypsum production. The 1956-60 curve represents the growth rate condition prior to the installation of controls; the 1966-70 curve represents the relationship assuming increased production with ineffective controls.

CHAPTER II

THE THEORETICAL MODEL

Of the few studies of industrial dust which have been undertaken most have dealt with cement-kiln dust, and they, along with the Jameson and Schiel study, provide the basis for the hypothesized relationships in this study. Damage to poplar trees by cement-kiln dust one mile from a cement plant was observed after cement production was more than doubled.[1] It was suspected that the dust was plugging the stomata and may have prevented the exchange of gases in the leaf tissue necessary for growth and development. The crust formed on the leaves by the dust may also have inhibited photosynthesis by light reflection. Another investigation dealing with cement-kiln dust settling on citrus trees has indicated a reduced starch formation as a result of light interference.[2] In the same paper a case was related where fruit set on cherry trees was found to be considerably reduced on that portion of the trees facing the cement plant. In several trial experiments it was found that the dust settling on the stigma prevented the pollen from germinating.[3] None of these studies considered environmental characteristics such as soil, topography, growth rate, and prevailing winds.

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[1] Air Quality Criteria for Particulate Matter: Summary and Conclusions, U.S. Department of Health, Education, and Welfare, Washington, D.C. (1970), p. 14.

[2] Ellis F. Darley, loc. cit.

[3] Ibid.

Changes in soil characteristics by airborne industrial pollutants have been suggested in studies by Darley[4] and Jameson and Schiel[5] and these changes have the potential to be either harmful or beneficial, depending on the dust composition. This fallout may, in time, account for either a reduced or increased vegetation yield.

Apart from these few studies, research on industrial dust deposition in the environment is rather meager, with most of it being confined to Europe.[6] One important omission in the list of particulates being studied is gypsum dust. Apart from the preliminary study by Jameson and Schiel, research and knowledge concerning gypsum dust in the environment is practically non-existent even though gypsum plants are widely distributed in virtually every biome in the United States.

The Jameson and Schiel study concerns a preliminary investigation of the effect of gypsum dust fallout on vegetation downwind of a gypsum processing plant located at Southard, Blaine County, Oklahoma. Tree cores were obtained for the purpose of growth ring analysis in areas 0-½ mile, ½-1 mile, and 1-1½ miles downwind from the plant. It was assumed that the trees closest to the plant received the heaviest concentration of dustfall as these were found to have significantly reduced growth rates. The trees sampled in the ½-1 mile area had a growth rate greater than the latter group but not significantly different from a control group located some six miles west of the

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[4]*Ibid.*

[5]Jameson and Schiel, *op. cit.*, p. 67.

[6]Ellis F. Darley, *op. cit.*, p. 145.

processing plant. An interesting and unexpected development arose out of the group of trees sampled 1-1½ miles from the plant. This group exhibited an accelerated growth rate when compared with all other groups. This accelerated growth rate was attributed by the authors to a conditioning influence by the gypsum dust on the soil. Gypsum dust ($CaSO_4$) is a well-known soil conditioning agent and is widely used in agriculture.

The Jameson and Schiel study represents an important and initial contribution to an area of study where little is known; however, there are some limitations to this study.

First, species from two different genera of trees were sampled and averaged: oaks (Quercus spp.) and elms (Ulmus spp.). While it has been established that certain species of the same genera of oaks have a similar growth rate under similar environmental conditions,[7] it has yet to be confirmed that oaks and elms, which are of different genera, exhibit similar growth rates. Therefore, utilizing the two different genera together in the analysis without confirmation of growth rate similarity may ultimately lead to faulty conclusions concerning the effect of the airborne dust fallout on tree growth.

Second, no soil analysis was attempted. Different soils will influence growth rate of vegetation.

Third, topographic variation was not considered. Such variations can profoundly affect the path and deposition of the airborne particulate matter.

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[7]Forrest L. Johnson and Paul G. Risser, "Correlation Analysis of Rainfall and Annual Ring Index of Central Oklahoma Blackjack and Post Oak," American Journal of Botany 60 (May 1973): 475-478.

Last, and perhaps most important, is the question of sampling. Sample selection in the Jameson and Schiel study was accomplished under less than rigid conditions, i.e., sampling was not strictly random. This may have made the results somewhat less than conclusive. It is important, therefore, that a more sophisticated approach to the study of airborne gypsum dust fallout and its ultimate effects on the vegetation be undertaken in order to confirm or contradict the findings of the preliminary study.

The Model and Assumptions

In order to examine the relationships between industrial gypsum dust fallout and vegetation growth, a theoretical model has been constructed with an accompanying set of assumptions. The model used in this paper was designed as an organizational device for the collection and handling of data, and as a psychological device to enable potentially complex interactions to be more easily visualized. It was designed with a consideration for flexibility.

The model (Figure II-1) consists of a set of concentric rings. The processing plant occupies the center of the innermost ring. Within the zones defined by each of the concentric rings, certain critical quantities of gypsum dust are assumed to be deposited. Zone A, enclosed by the innermost ring, is the region of greatest dustfall. As a result, the most detrimental effects to the vegetation are expected to occur here. Zone C, which is bounded by the second and third rings, is the region where the beneficial effect, if it exists, is suspected to occur. In this zone there would be less gypsum dust caking the leaves of the trees and interfering with photosynthesis, yet perhaps a critical amount reaching the soil and possibly acting

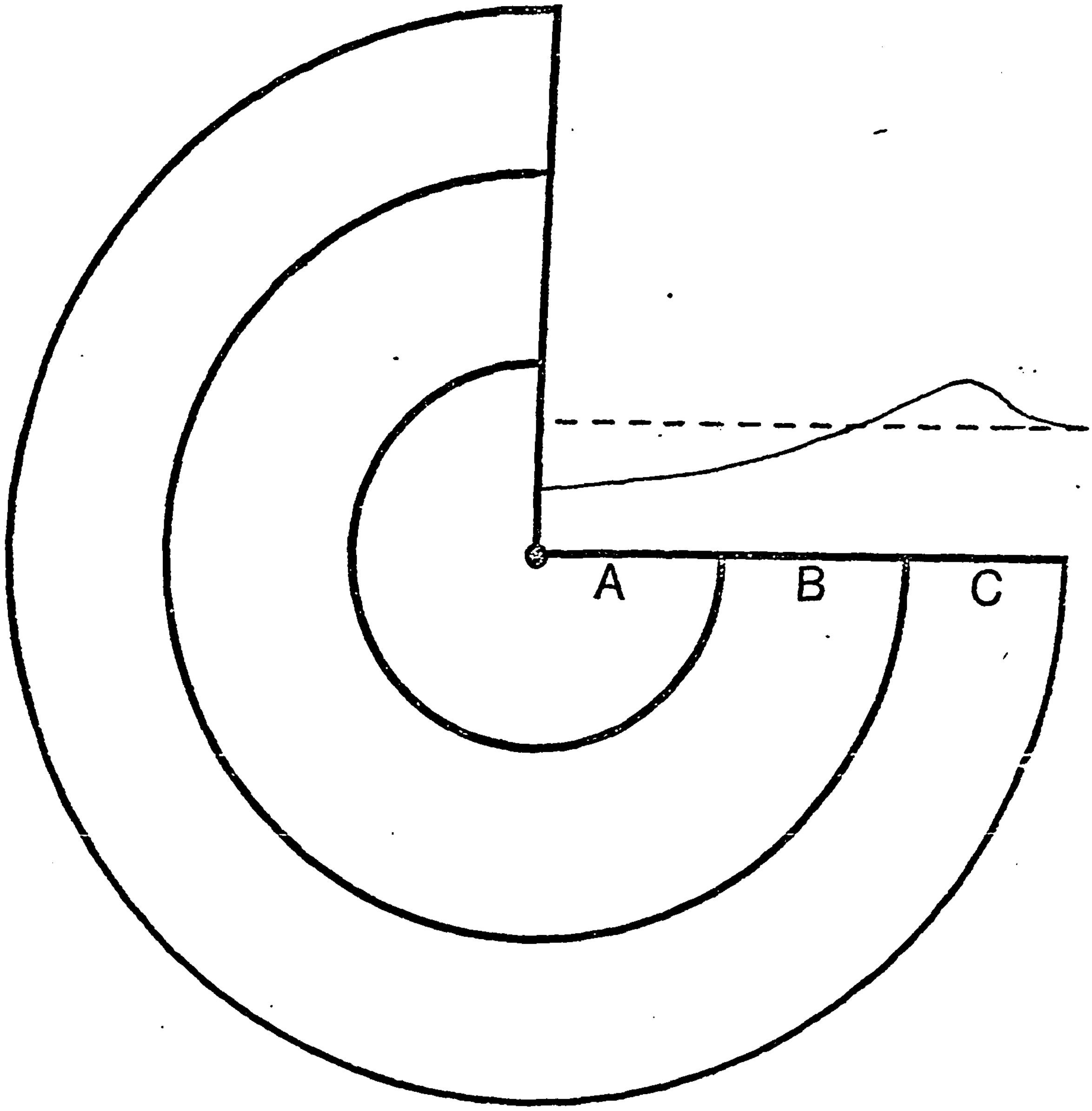

Figure II-1. The theoretical model. Graph represents relationship between vegetation growth rate and distance from the plant. Dashed line represents normal growth rate.

as a soil conditioner. In other words, the proposed conditioning effect on the soil would predominate over the growth inhibition effect on the leaves in this region. Zone B is a region where the vegetation is expected to approximate a normal growth rate and it represents a balance between the detrimental and beneficial effects of the dust. Vegetation lying beyond Zone C is out of the effective range of the dustfall. The distance from the center and the configuration of the perimeter of each of the concentric rings will be a function of wind speed, wind direction, and topographic influences.

The set of assumptions which accompany this model are:

1. Stokes Law, which governs the fallout rate of particles in the atmosphere, is operative. Very simply, Stokes Law states that the heavier the particle, the sooner it will fall to earth under given atmospheric conditions. The Stokes equation is:

$$Vq = \frac{2r^2 g\rho}{9u}$$

Where: Vq = fall velocity (LT^{-1}); r = particle radius (L); g = gravitational acceleration (LT^{-2}); ρ = particle density (ML^{-3}); u = atmospheric dynamic viscosity ($ML^{-1}T^{-1}$). M, L, and T are mass, length, and time, respectively.[8]

2. The region under consideration has an isotropic surface, i.e., it is a relatively flat, featureless area. This would be necessary if the rings are to maintain their strict concentricity.

3. The soils found in this area are homogeneous as far as basic structure and content are concerned.

4. Equal competition exists among the sampling population for the available moisture in the area. Given equal moisture

[8]David H. Slade (ed.), Meteorology and Atomic Energy (Oak Ridge, Tennessee: U.S. Atomic Energy Commission, 1968), p. 202.

availability, trees of the same genera through the region should grow at approximately the same rate. This is an important assumption because if the competition for moisture is unequal for whatever reason, trees in different parts of the region would be growing at different rates even under non-dust fallout conditions, and it would be difficult to isolate the effects of the gypsum dust fallout if such a condition existed. This assumption is related to assumptions two and three in that assuming a flat surface, one is assuming equal runoff rates, and in assuming homogeneous soils, one is assuming equal rates of infiltration, percolation, field capacity, and water available to the vegetation.

5. In order to experience a strictly concentric pattern such as the one depicted in Figure II-1, the wind must blow equally (occurrence and speed) from all directions, thus giving the dust an opportunity to be deposited equally in all directions from the plant.

Such assumptions are, in fact, to varying degrees unrepresentative of the actual conditions. An area such as the one represented in this model, with a great deal of soil and surface homogeneity, will give rise to trees growing at approximately the same rate throughout. The only perturbation with regard to altering the growth rate of the trees in the model lies primarily in the potential of the dust fallout from the gypsum processing plant. The United States Gypsum processing plant at Southard, the one used in the pilot study, has been selected as the study area for reasons presented in Chapter III (Methodology). Does the region affected by the Southard processing plant meet the assumptions of the model?

With regard to the first assumption, it suffices to say that Stokes Law is a universally accepted principle pertaining to gravitational settling of airborne particles. Given equal atmospheric conditions throughout an area, there will be a decreasing density of dust accumulation outward from a maximum deposition area. In other words, there is a distance decay function.

The second assumption, that of surface isotropism, can be loosely applied to the Southard area. Regions of gypsum strata are generally flat and featureless. Such deposits are of marine origin and unless the region has been modified by tectonic activity or any significant erosion, it is relatively flat. The Southard region can be described as having flat to gently rolling topography with no sharp breaks save for a few man-made quarries and a sometimes steep-sided cut through which runs a southwest-northeast oriented railroad (Figure II-2). The quarries were ignored in the sampling procedures because they are of relatively recent occurrence and there is little or no vegetation there suitable for sampling.

The third assumption, that of soil homogeneity, is reasonably valid for Southard. The soils encountered in the region under investigation are mainly of a sandy or sandy-loam type with very little deviation in properties throughout.[9]

The fourth assumption, that of the existence of equal competition among the trees for available moisture, is directly related to assumptions two and three. If, indeed, the substrate and topography (which influence infiltration and drainage) are homogeneous, there should be little or no growth differentiation throughout the region, other than that initiated by the gypsum dust fallout.

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[9]Carl F. Fisher, Soil Survey of Blaine County, Oklahoma (Washington, D.C.: U.S. Government Printing Office, 1968), pp. 48-55.

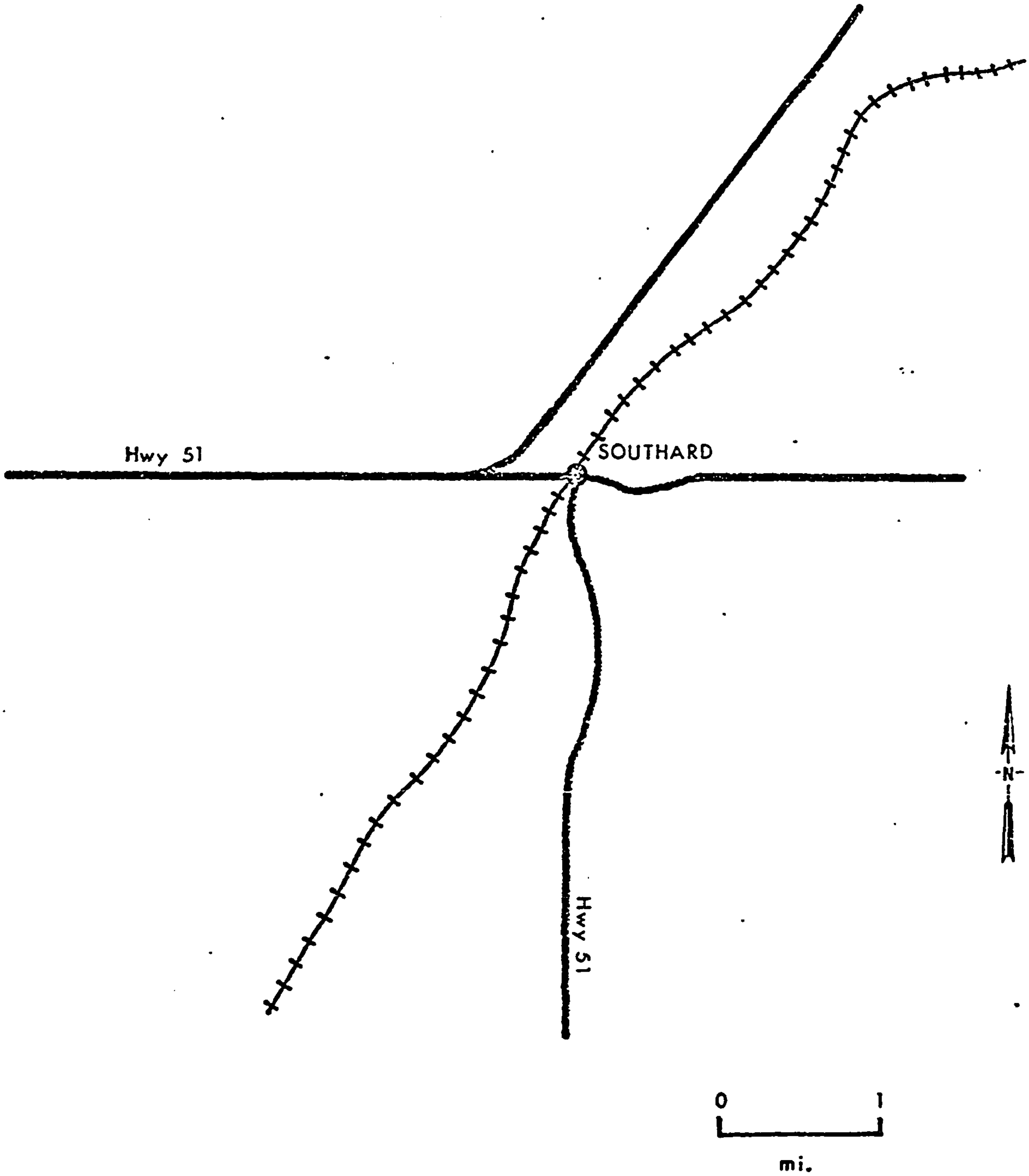

Figure II-2. The Southard area showing relationship between the gypsum processing plant and the southwest-northeast oriented railroad. The plant is located approximately at the center of the dot.

In looking at the historical growth pattern of the vegetation in this region, an analysis by Jameson and Schiel indicated that there was considerable variation in the growth rate of the vegetation at different distances from the plant for the growth period 1966-70, yet there was no significant variation in the growth rate for the period 1946-50 (Figure II-3).[10] The gypsum production level for the 1946-50 growth period was less than half of that for the 1966-70 period. During the period 1946-50 there was a minimum influence of the gypsum dust fallout and the tree growth was more or less equal throughout the region. This suggests that under a non-polluting or at least a reduced polluting condition, one could expect to find a uniform growth rate as a result of homogeneous topography, soil, and available moisture. This suggests the probability of a threshold level of deposition responsible for modifying the growth rate of trees.

Assumption number five is the weakest of all the assumptions. An analysis of wind direction for the Southard area indicates prevailing winds from the south to southeast, with a secondary prevailing wind from the north during the winter months. This type of unequal wind pattern will cause variation in the deposition pattern of the dust and upset the strict concentricity and circularity of the rings.

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[10] Jameson and Schiel, op. cit., p. 66.

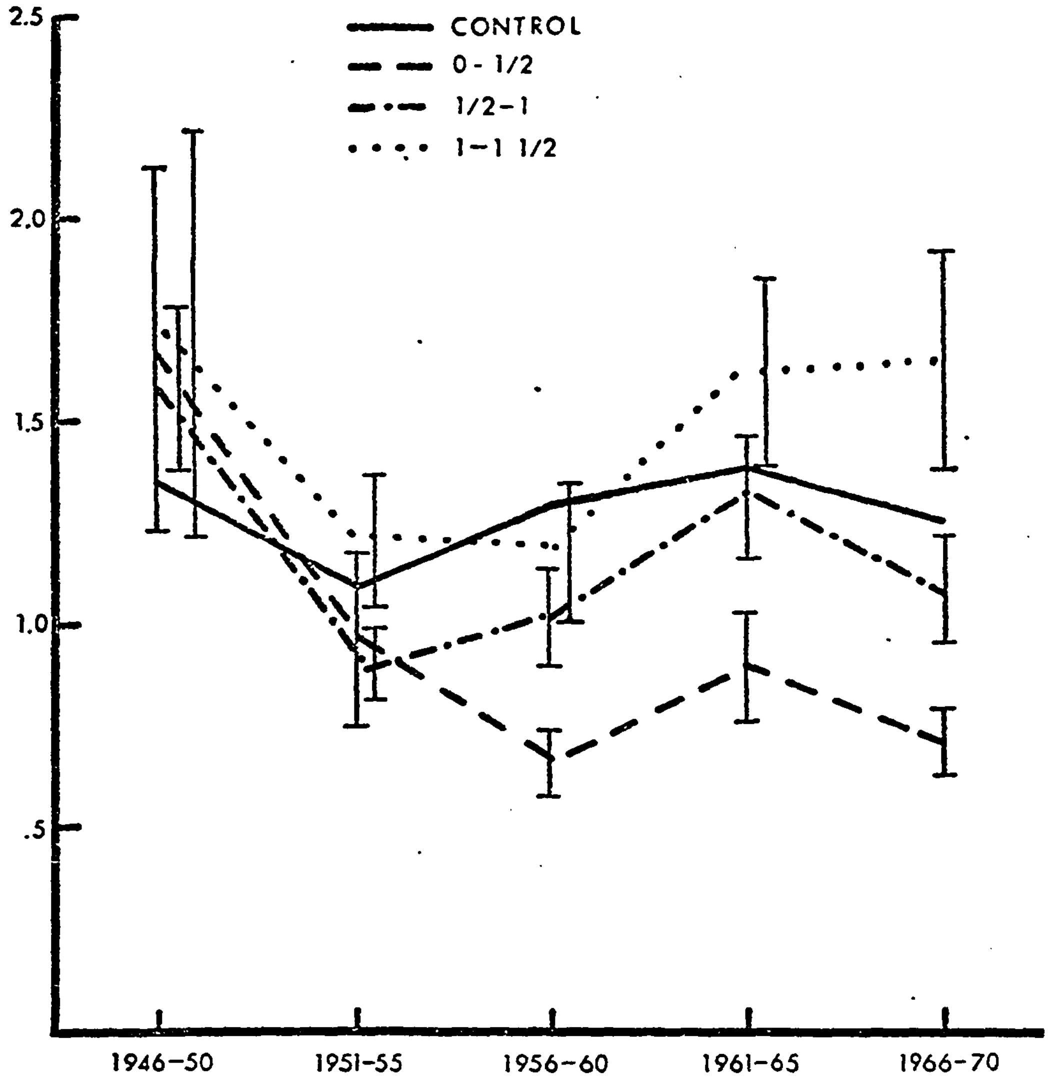

Figure II-3. Historical development of tree growth in the three sampling regions. Vertical lines represent standard error. (Source: Jameson and Schiel, 1971).

CHAPTER III

RESEARCH DESIGN AND PROCEDURES

Site Selection

In selecting an appropriate sampling site there were four important considerations:

1. The sampling area should be in a rural location where the only air pollution present is that associated with the gypsum processing industry. This eliminates the influence of other pollutants on the vegetation and soils.

2. Yearly production values associated with the industry under investigation should be available. It has been hypothesized that different levels of dust fallout will elicit different responses in the vegetation, and this dust fallout will be in part a function of the production level.

3. There should exist in the region a suitable type and number of trees for sampling.

4. The final consideration is convenience. The area needs to be within a reasonable distance from the working base of the investigator.

In light of these considerations, the site selected for investigation is the United States Gypsum Company processing plant at Southard, Blaine County, Oklahoma, the site of the preliminary study. The plant, approximately 70 air miles northwest of Oklahoma City, has been operative since 1916. It is rurally located with no other industries in the vicinity.

Production values for the plant in tons per year are available from 1930 to the present, with the exception of the years 1944-46.

The natural tree vegetation in the vicinity of the plant consists primarily of post oak (*Quercus stellata*) and blackjack oak (*Q. marilandica*), along with some elm (*Ulmus americana*). The sampling region lies within part of a long, narrow, northwest-southeast oriented belt of a post oak-blackjack oak forest type located between belts of mixed grass prairie to the east and west (Figure III-1). The forest belt is located on soil derived predominantly from sandstone.[1]

In order to conduct as complete an analysis as possible on the effects of airborne gypsum dust fallout on the vegetation, four important facets of analysis were deemed necessary. They were an evaluation of (1) the yearly production levels associated with the Southard plant, (2) pedology, (3) climatology, and (4) vegetation.

Gypsum Production

In Chapter II an allusion was made to the possibility of the existence of a threshold level of the dust fallout on the vegetation. This would, in part, be a function of the amount of dust leaving the stack. This, in turn, is related to the production tonnage of the plant.

Yearly production values (tons per year) for the processing plant at Southard were obtained from the Oklahoma Department of Mines

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[1]Fenton Gray and H. M. Halloway, *Soils of Oklahoma* (Stillwater: Oklahoma State University, 1959), p. 12.

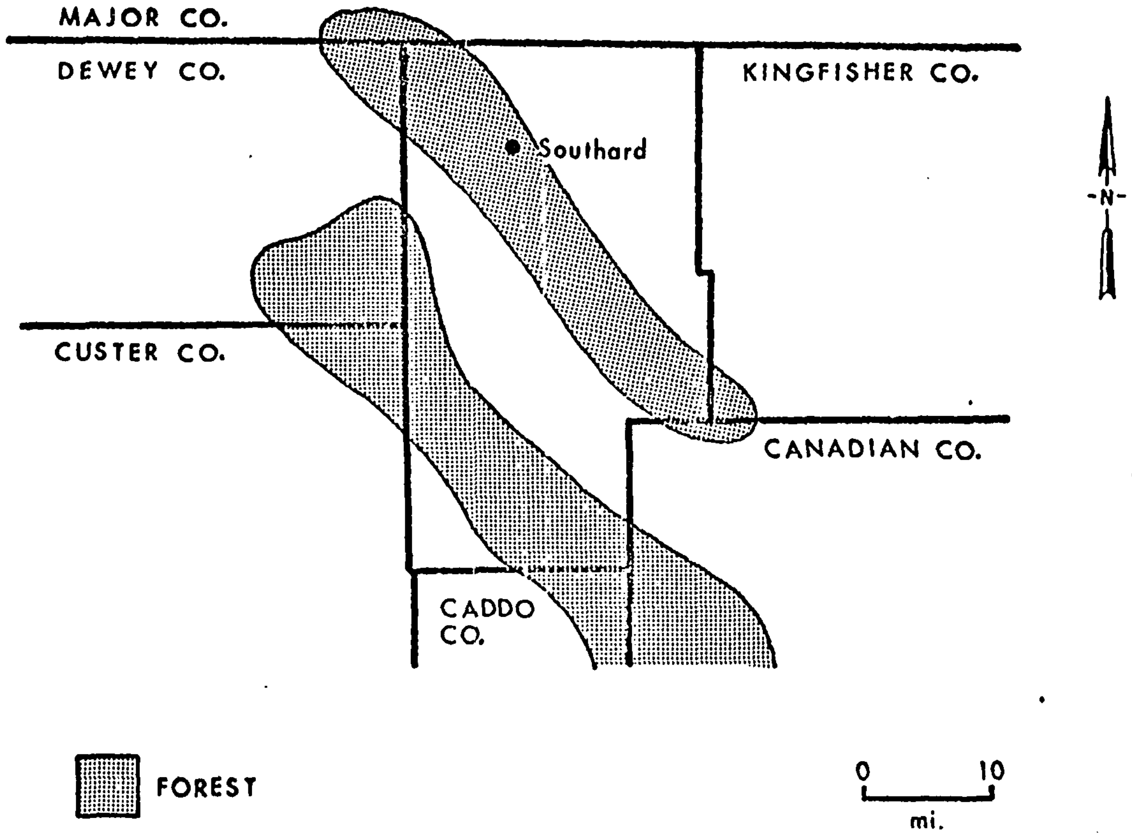

Figure III-1. Belts of post oak-blackjack oak forest which cut through Blaine County and embrace the Southard area. The remaining areas are in mixed-grass prairie. Source: Gray and Halloway.

at Oklahoma City (Appendix A). Using the same system of grouping specified years into growth periods as did Jameson and Schiel, averages of production tonnage were computed for five-year growth periods from 1946-70.

Pedology

For information on soil types and characteristics, the author relied primarily on the information contained in Soil Survey of Blaine County, Oklahoma.[2] This publication represents the most sophisticated and extensive description of the soils in this area to date.

The rationale for a pedological analysis was to establish similarities and/or differences in the soil types found in the study area in the belief that soils with vastly different properties will give rise to vegetation growing at different rates. Therefore, a knowledge of the substrate is considered important to the study.

Climatology

The climatological data pertinent to this study are wind direction and speed and precipitation. Wind direction and speed will influence transport and the ultimate deposition pattern of the dust, and precipitation has a profound influence on the growth rate of the vegetation.

In order to determine the path of effluent transport and ultimate deposition, a wind analysis was necessary. Analyses were made on both a regional and local scale. For the regional analysis wind data from the United States Weather Bureau State Climatological Summaries were collected for Wichita, Kansas; Amarillo and Wichita

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[2] Carl F. Fisher, op. cit., pp. 1-87.

Falls, Texas; and Tulsa and Oklahoma City, Oklahoma. Data were available for the period 1950-70. The rationale for the choice of these cities is that each is a first order weather station and adequate and reasonably complete data could be obtained. In addition, the aforementioned stations are located approximately at the four cardinal points with Southard at the center (Figure III-2). Oklahoma City was also included because it is the closest first order weather station to Southard. With a knowledge of the wind direction and speeds for these five stations, a general wind pattern could be interpolated for Southard. In addition, the U.S. Army Corps of Engineers at Canton Dam, Oklahoma, located approximately seven miles west of Southard, supplied their wind data for the years 1963-69. These data were used to construct a wind rose for the local area.

Differences in the vegetation growth in an area from year to year are dependent to a great extent on the amount of rainfall that area receives. A great amount of rainfall would be expected to be followed by a relatively greater growth rate of vegetation than that which would accompany a lesser amount of rainfall. Therefore, precipitation data were collected for the five first order weather stations listed above, as well as for Canton Dam. The precipitation data were averaged into groups of five years corresponding to the established growth periods already set up. Graphs were constructed using these data in order to visualize the historic fluctuation of the precipitation.

Vegetation

In order to make determinations on the effect of gypsum dust fallout on members of a natural biological community, sampling activity was concentrated on vegetation; specifically on trees of one genus.

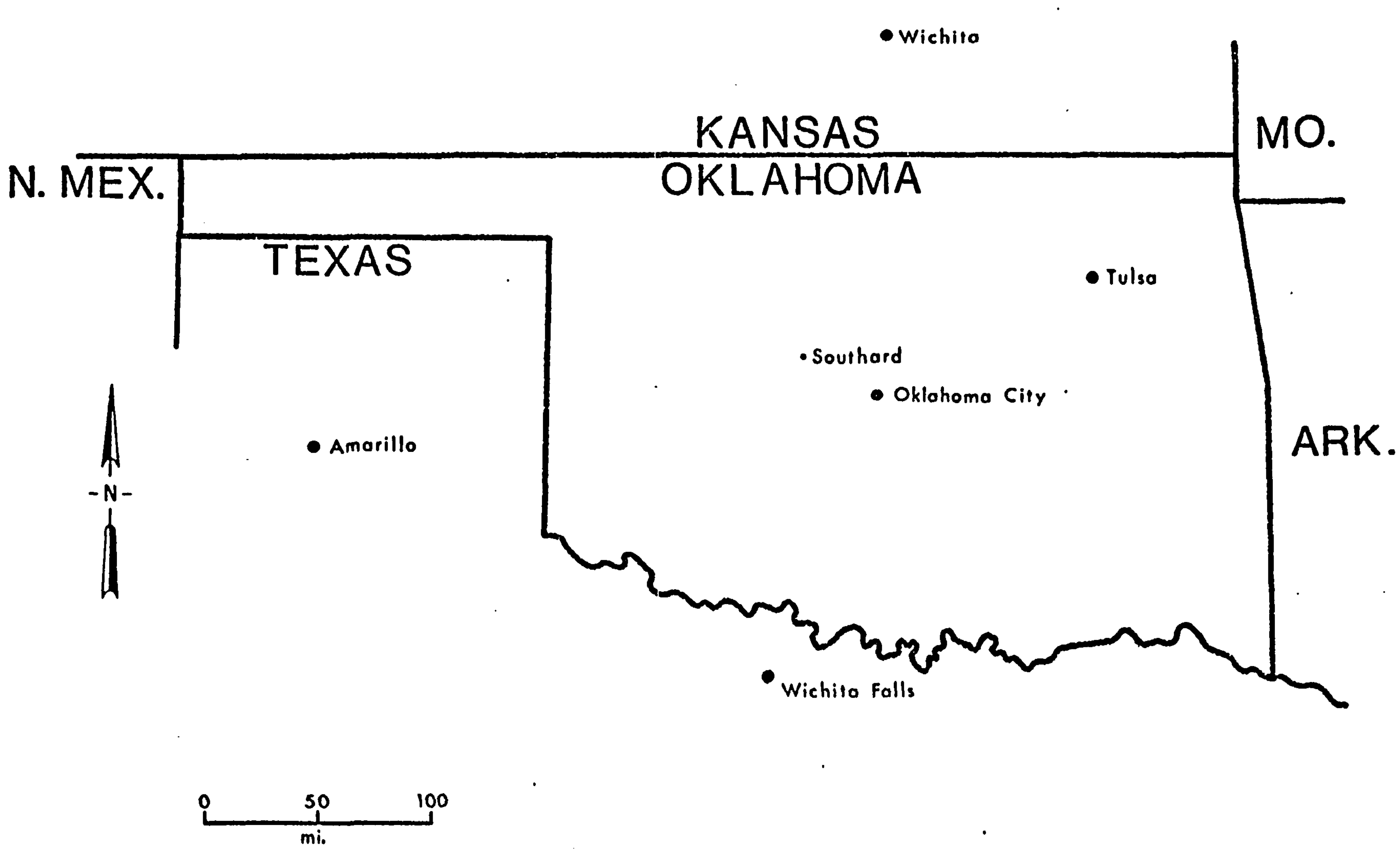

Figure III-2. Five first order weather stations selected for climatic data collection and their location relative to Southard.

Gypsum dust apparently has no effect whatsoever on animals[3]; therefore, animal populations were ignored in the sampling procedure.

Sampling Design

Sampling consisted of obtaining tree cores from the two dominant species of oak in the area--post oak and blackjack oak. A study by Johnson and Risser indicated there is no difference in the growth rate of these two species of oak growing under similar environmental conditions.[4]

Tree cores were taken for the purpose of growth ring analysis in order to determine the effect of the gypsum dust fallout on the trees. The selection of oaks as the sampling population is based on the fact that they comprise the dominant tree genus in the area. It is also wise to confine sampling activity to only one genus of tree in order to establish a certain amount of consistency among the sampling population.

A stratified random approach to sampling was used. A grid, four miles by four miles, was superimposed over the region around the gypsum plant with the plant located at the center of the grid. The grid is divided into 1/2-mile square blocks (Figure III-3). Within each block, vegetation samples were obtained randomly. Each 1/2-square mile block was further subdivided into 100 smaller blocks (hereafter called sampling blocks), each one being 264 feet square (Figure III-4). Three of these sampling blocks were selected randomly

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[3] J. S. Sheahan, "Effect of Gypsum Dust on the Environment," Minerals Processing (March 1971): 15.

[4] Forrest L. Johnson and Paul G. Risser, loc. cit.

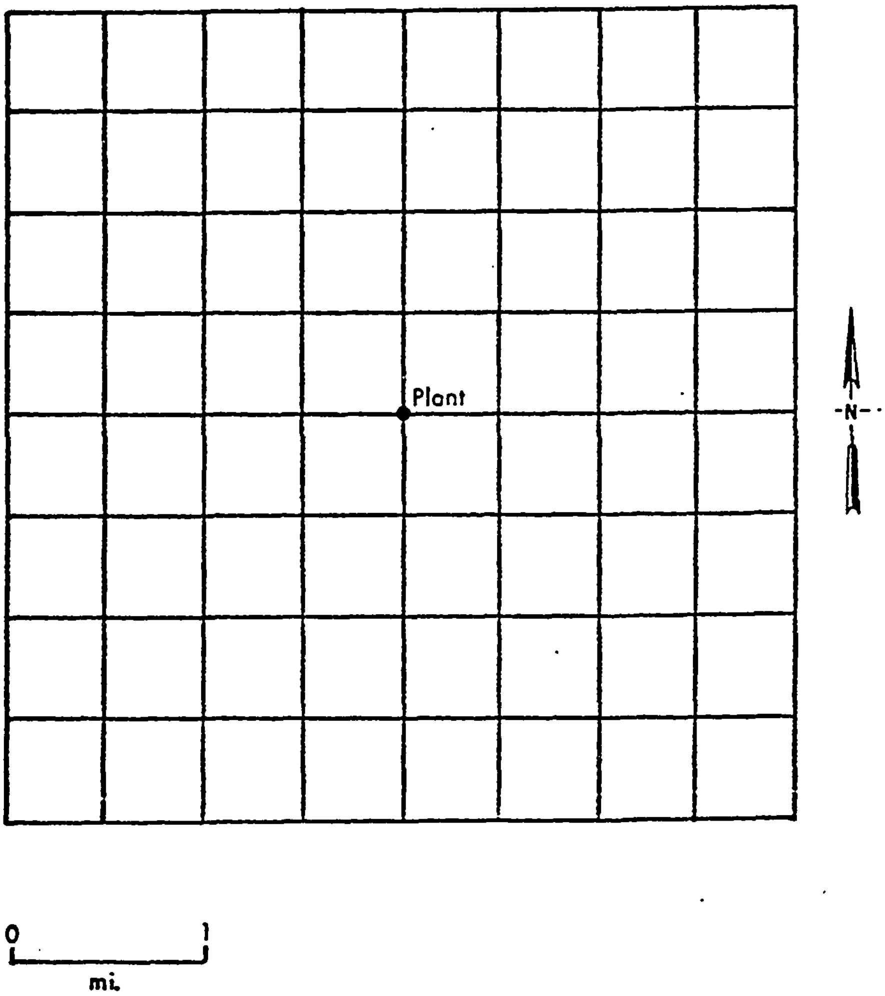

Figure III-3. Primary sampling grid.

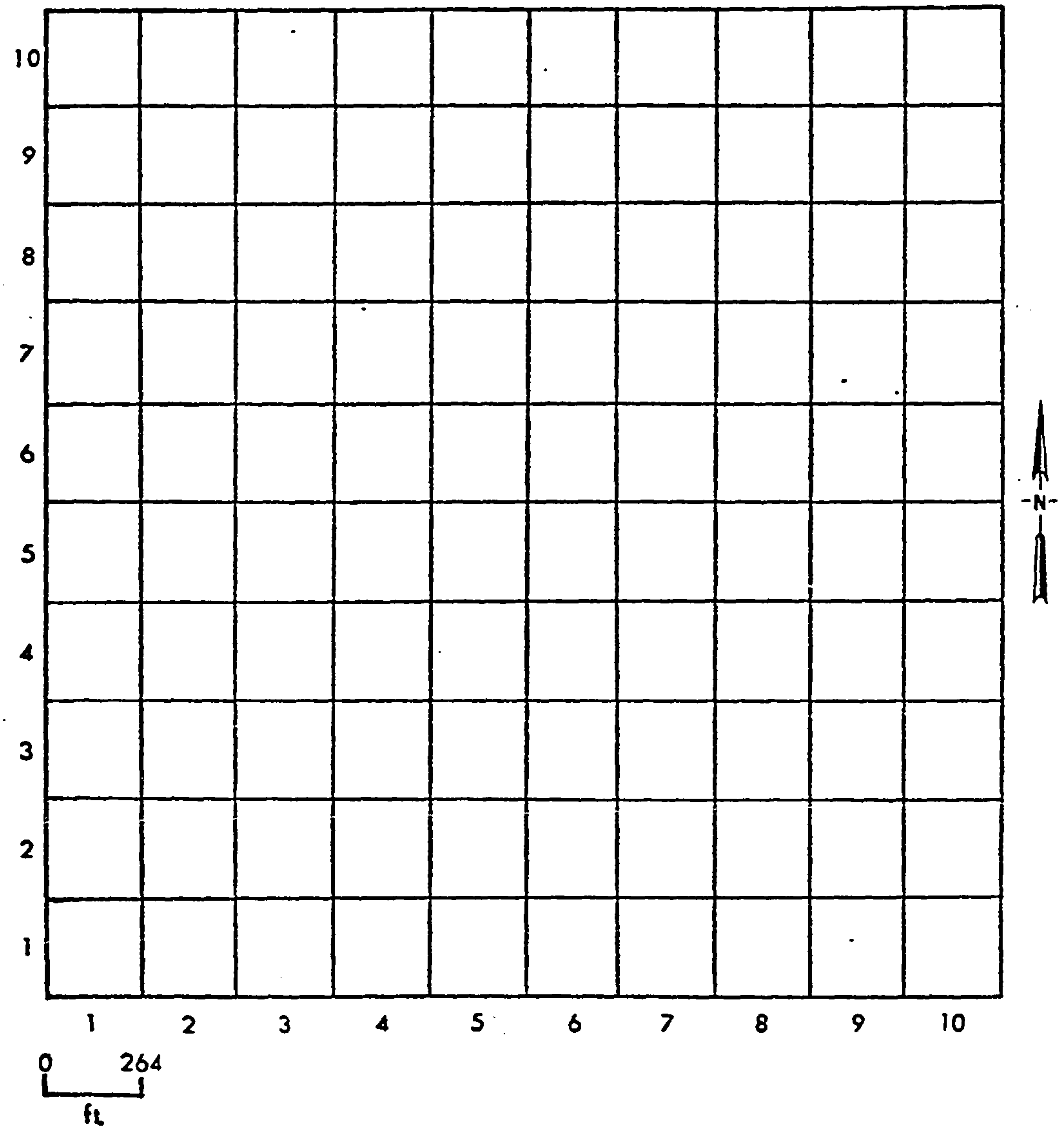

Figure III-4. Sampling Blocks

and a tree core obtained from a member of the sampling population occurring in each block. A random number table was consulted to pick the three sampling blocks within each 1/2-square mile block. The first number in a random number line corresponds to the location along the X axis. The second number in the random number line corresponds to a location along the Y axis. If the first number was a one and was followed by a zero, then that location was interpreted as a 10 on that particular axis. If the first number was a one and was followed by any number other than a zero, then that number was interpreted as a one. The process was repeated until three sampling blocks in each 1/2-square mile block were selected. The sampling blocks were chosen prior to going into the field for the actual data collection. Once in the designated area, a tree core was extracted from a tree that met specified criteria: preferably the oldest tree available so as to yield a maximum amount of historical data[5]; cylindrical, straight trunk; and apparently healthy and undamaged. Some samples were unobtainable from certain areas for various reasons: none of the sampling population present, denial of access to private property, or disturbed habitat.

Tree cores were taken at breast height using a .200" diameter tree borer. In the field the extractions were secured in a soda straw to prevent curling and warping, and labeled as to the location where they were obtained and the species. In preparation for the tree ring analysis the cores were mounted in a notched length of wood with glue; this procedure facilitates ring measurements. The information regarding

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[5]There is no way prior to tree-core analysis that one can determine the oldest tree in a region. Therefore, the decision in selecting the oldest tree is arbitrary and is left to the discretion of the investigator.

location and species was transferred to the length of wood. For each core, measurement began outside the pith and continued to the 1970 ring. At the point of each growth ring on the core, a tic mark was placed on the wood block in order to facilitate measurement. Measurements were taken for the established growth periods. Averages were then computed for each 1/2-square mile block.

An analysis of the tree rings can reveal the effects of the gypsum dust fallout on the growth rate of trees. It is accepted that air pollution, specifically particulate air pollution, can affect tree growth,[6] and studies have been made which indicate that particulate air pollution has been found responsible for reduced growth rate in trees.[7]

In addition to the cores obtained in the designated sampling blocks, tree cores were obtained from a nearby area for purposes of comparison. This control group was selected randomly in a manner comparable to the original selection process. This control group of tree cores is interpreted as being representative of the normal unpolluted growth condition for this area. The group consists of oak trees and was located on substrate similar to that of the sampling population. The control group, however, was located in an area free of any dustfall.

Statistical Design

Growth rings for the tree cores were measured in centimeters and these values were placed on forms designed to carry the information

[6]Harold C. Fritts, personal communication, February 2, 1972.

[7]James A. Heimbach, "The Correlation of Polluted Air with Tree Growth and Lung Disease in Humans," Journal of Computers in Biology and Medicine 1 (1971): 243-253.

(Appendix C). The averages for each of the five-year growth periods of the three randomly selected samples from each 1/2-square mile block were taken as being representative of the tree growth in that block.

After averages were taken and plotted for each block for each growth period (Figures III-5 through III-9), the growth rate data were then subjected to a trend surface analysis. Trend surface analysis is a special case of multiple curvilinear regression. The multiple portion of the analysis is limited to three variables: a dependent variable (in this case the growth rate of trees), and two independent variables (the X and Y locational variables). The curvilinear portion of the analysis is the fitting of the data to the polynomial functions.

Trend surface analysis was used to examine the type of areal variation in the tree growth response which is attributed to the airborne gypsum dust fallout. The advantage of trend surface analysis over simple regression is that the entire four-square-mile area comes under analysis rather than just line segments of the area. In addition, maps of the area printed by the computer showing the variation in growth rate were used.

A trend surface analysis was performed on the plotted growth rates for each period. The period 1946-50 was expected to show little significant spatial variation in growth rate of trees due to the relatively small amount of gypsum processing occurring during this time period. After that, however, as the production levels of the plant increased, the variation in the growth rate of the trees was expected to become increasingly significant if the dust was indeed responsible for the variation.

	1.05	2.10	.85	1.15	.87		
1.33	1.01	1.30	1.38	.75		1.33	
1.11	.85	1.10	.75	1.28	2.11	1.45	1.80
1.13		1.10	1.03	1.06 Plant	1.35	.95	1.65
1.23	2.15	.51	.85	1.11		1.70	1.08
1.22	.70	.55	1.07	1.57			
1.18	1.95	.80	1.01	1.56			
	1.41	1.00	1.10	1.49			

-N-

0 1
mi.

Figure III-5. Plotted growth rate averages for the 1946-50 growth period (cm.).

	.96	1.50	.80	.83	1.12		
.83	.86	.85	.76	.50		1.10	
1.06	.72	1.01	.75	.90	1.16	.90	1.10
.93		.75	.68	.68 Plant	1.25	.80	.60
.96	1.03	.40	1.10	.81		1.20	.73
1.07	.60	.33	.80	1.22			
.90	1.46	.61	1.00	1.06			
	1.18	1.15	1.12	.98			

-N-

0 1
mi.

Figure III-6. Plotted growth rate averages for the 1951-55 growth period (cm.).

	1.40	1.50	.97	.71	1.65		
.90	.83	1.10	1.16	.85		.90	
.93	1.05	1.18	.61	1.23	1.30	.95	1.50
1.28		.88	.80	.50 Plant	1.35	1.05	.65
1.36	.98	.41	.91	.78		.80	.78
1.15	.40	.51	.95	1.60			
1.30	1.65	.70	.71	1.03			
	1.08	.87	1.43	.93			

N

0 1
mi.

Figure III-7. Plotted growth rate averages for the 1956-60 growth period (cm.).

	1.48	1.40	1.35	.98	1.02		
.73	.88	1.10	.88	1.30		1.25	
1.11	1.36	1.38	.60	1.63	1.63	1.10	1.65
1.26		.88	.78	1.00	1.30	1.60	.55
1.03	1.28	.45	.80	.85		1.60	.83
1.73	.65	.51	.88	1.32			
.97	1.05	.80	.80	1.10			
	1.00	1.10	1.70	1.46			

Plant

-N-

0 1
mi.

Figure III-8. Plotted growth rate averages for the 1961-65 growth period (cm.).

	1.06	1.05	1.45	.66	.80		
1.05	.76	.85	.73	.80		1.40	
.98	1.28	1.15	.86	1.70	1.20	1.30	1.30
1.33		.78	.60	.75 Plant	1.00	1.55	.70
.95	.78	.43	.56	.86		1.40	.70
1.30	.55	.40	1.00	.90			
1.30	1.31	.65	.58	1.06			
	.90	.82	1.30	1.31			

-N-

0 1 mi.

Figure III-9. Plotted growth rate averages for the 1966-70 growth period (cm.).

A modified FORTRAN IV trend surface program designed for the IBM 1620 computer was used.[8] This program fits first through sixth degree polynomials (trend surfaces) to a set of X,Y,Z coordinate values. The output consists of (1) equations of the polynomials, (2) standard deviation, (3) explained, unexplained, and total variance, (4) coefficient of determination and correlation coefficient, (5) a table of the values of the surfaces evaluated at each XY coordinate and the corresponding residuals for each degree, (6) plots on the XY plane of the Z coordinates and each order of residual, and (7) computer maps of the trend surfaces for each degree for each growth period were printed.

The results of the trend surface analysis were then subjected to an analysis of variance test for significance after the method described by Krumbein and Graybill.[9] The surface that tested out as the most significant for each growth period was then selected for the final analysis.

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[8] Paul Krause, DOGPOL: User's Guide to Department of Geography Program Library and Other Computer Software (Norman: Department of Geography Technical Paper No. 1, University of Oklahoma, 1974), pp. A-35-A-39. This program was derived from a program designed by Donald I. Good of the Kansas Geological Survey. For more information on this program the reader is referred to Good's publication, "FORTRAN II Trend Surface Program for the IBM 1620" (Lawrence: Special Publication No. 14, State Geological Survey, The University of Kansas, 1964), pp. 1-54.

[9] W. C. Krumbein and Franklin A. Graybill, An Introduction to Statistical Models in Geology (New York: McGraw-Hill Book Company, 1965), pp. 333-337.

CHAPTER IV

ANALYSIS

The findings of each of the facets of investigation are treated in the order in which they were presented in Chapter III. The growth rate of trees, the dependent variable, is assumed to be a function of location with respect to distance from the processing plant. This, in turn, is related to gypsum production, pedology, climatology, and topography.

Gypsum Production

Using the data obtained from the Oklahoma Department of Mines, averages of gypsum production for the defined growth periods in tons per year were calculated and graphed (Figure IV-1). For unstated reasons, the United States Gypsum Company at Southard would not release any production data; therefore, a monthly or seasonal breakdown of the gypsum production is impossible. From the graph it can be seen there is a general increase in gypsum production during the study period from an average of 233,575 tons per year during the 1946-50 growth period to 448,068 tons per year for the 1966-70 growth period. The one exception is associated with the growth period 1956-60 when a slight decrease in production occurred from an average of 289,636 tons per year for the 1951-55 growth period to an average of 288,517 tons per year for the 1956-60 growth period. The production values for the last growth period (1966-70) were more than twice as much for the

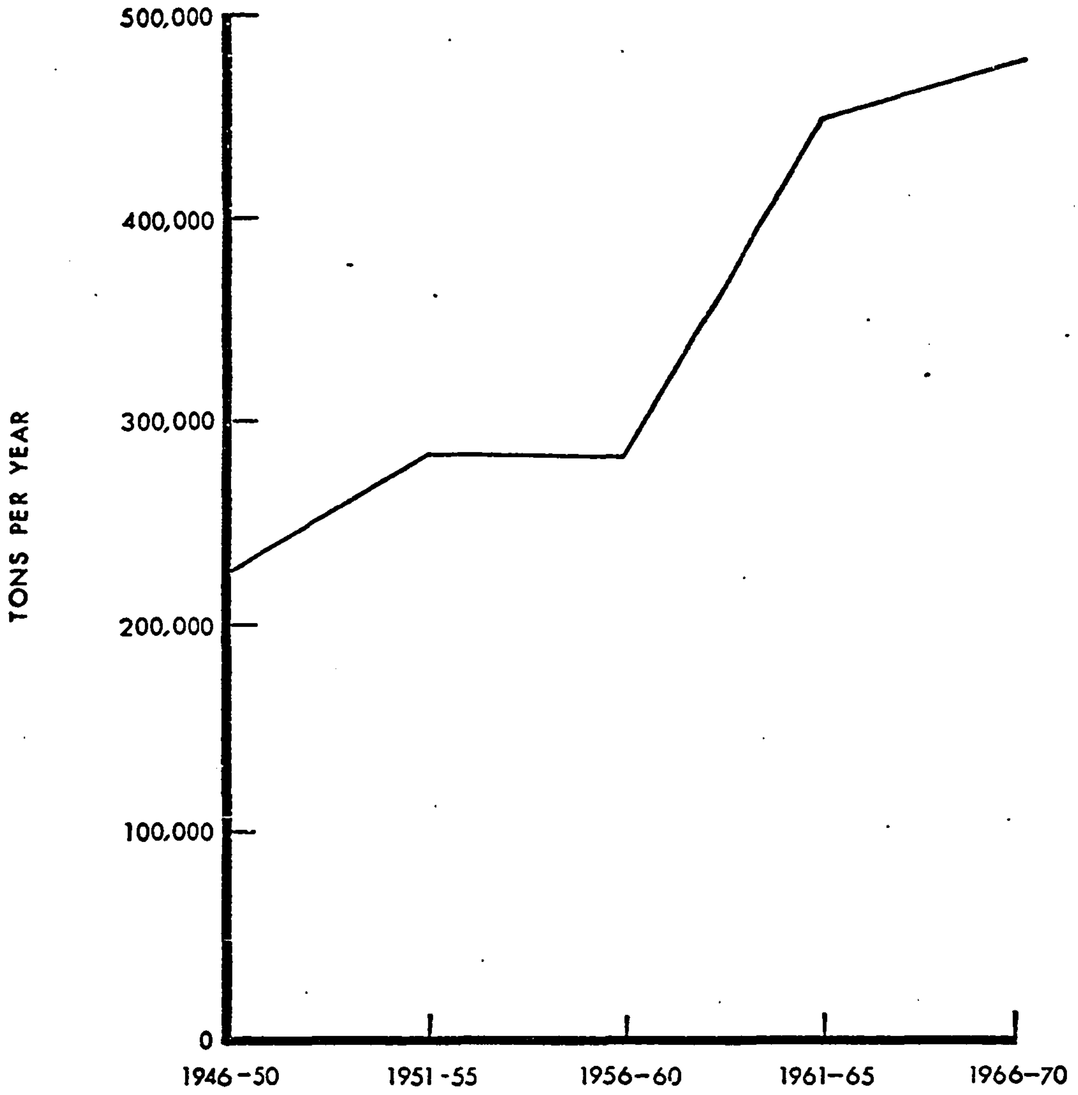

Figure IV-1. Production values for the United States Gypsum Company processing plant at Southard, Oklahoma. (Source: Department of Mines, Oklahoma City, Oklahoma.)

earliest growth period (1946-50)--478,068 tons per year compared to 233,575 tons per year.

Calcium and sulfur, which account for most of the particulate pollution entering the atmosphere from the processing plant stack, are among 16 elements known to be essential for plant growth.[1] In moderate quantities, the gypsum dust probably has little, if any, effect on the soils or vegetation. In heavy concentrations the dust, if mixed mechanically into the soil or introduced into the soil through percolation, is known to have a beneficial effect. Part of the effect is accomplished by the gypsum dust enlarging pore spaces in the soil, providing for better circulation of air and water. Gypsum dust is used often on sodic soils for the purpose of changing part of the caustic alkali carbonates into sulfates. However, several tons of gypsum per acre are necessary and the gypsum must be cultivated into the soil.[2] The calcium in the dust promotes cationic exchange which is an important plant-soil relationship. Research has shown that the capacity of a soil to exchange cations is the best single index of potential soil fertility.[3] The absorption of calcium by plants may occur either upon the direct contact of roots with soil particle surfaces or from soil solution.[4]

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[1]Roy L. Donahue, John C. Schickluna, and Lynn S. Robertson, Soils: An Introduction to Soils and Plant Growth (New Jersey: Prentice-Hall, 1971), p. 4. The other elements essential to plant growth include carbon, hydrogen, and oxygen from the air and water; phosphorous, potassium, iron, manganese, boron, magnesium, copper, zinc, molybdenum, and chlorine from the soil; and nitrogen from both the air and the soil. Calcium and sulfur are both obtained from the soil.

[2]Henry O. Buckman and Nyle C. Brady, The Nature and Properties of Soils, 7th ed. (New York: The Macmillan Co., 1969), p. 410.

[3]Donahue, Schickluna, and Robertson, op. cit., p. 59.

[4]R. L. Hausenbuiller, Soil Science: Principles and Practices (Dubuque: Wm. C. Brown Co., 1972), p. 295.

In addition to being an important element for plant growth, sulfur is recognized to be advantageous on salty lands, especially where sodium carbonate abounds. The sulfur upon oxidation yields sulfuric acid which changes the sodium carbonate to a less harmful sulfate and also reduces the alkalinity.[5]

Agricultural gypsum, essentially the same in content as the gypsum particulate matter emitted from the stack, is often applied to the soil as a soil conditioner. One leading manufacturer of agricultural gypsum recommends applying at least 400 pounds of gypsum per acre for increasing cotton yield from one quarter to one-half bale per acre.[6]

In the forested portions of the study area the dust is more likely to settle on the canopy and adhere to the leaves before reaching the ground in any appreciable quantity. Some dust will certainly reach the ground, but the effect of the dust adhering to the leaves of the trees is believed by the author to be far more significant in affecting growth than the dust which reaches the soil.

The nutrients that vegetation requires for growth and sustenance are obtained by absorption mainly through the root systems. The dust caking the leaves of the trees has no immediate value for the tree. In addition, photosynthesis takes place in the leaves, and for this process to occur, carbon dioxide from the ambient air must diffuse into the leaves through the stomata. If the leaves are caked with dust, this carbon dioxide intake may be reduced as a result of the dust

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[5]Buckman and Brady, loc. cit.

[6]United States Gypsum Company commercial matter.

clogging the stomata. It is more likely, however, that the photosynthetic process is reduced by the reflectivity of the dust which reduces contact of the light waves essential to the process. Reasons for this are presented at the end of this chapter. In either case, the growth potential of the vegetation is reduced.

Pedology

An analysis of the data acquired from the Blaine County Soil Survey description and maps shows a predominance of Nobscott fine and Pratt loamy fine sand soils in the area.[7] Other soil types are also present, but they exist mainly as small scattered pockets. Both the Nobscott and Pratt soils are characterized as having fine sand and loamy fine sand texture. Both soil types have an available water capacity of .07 inch per inch of soil. Permeability is rated as moderately rapid, and they are both classified in soil hydrologic group A, described in Appendix B. The only difference between the two soil types is reaction (pH): the Nobscott fine sand has a pH of 5.6-6.5 while the Pratt loamy fine sand has a pH of 6.6-7.3. These soils are considered similar enough that no major differentiation in vegetation growth rate is expected as a result of soil variability.

Climatology

Wind

Wind direction and speed govern, to a great extent, the direction and the rate at which pollutants are dispersed in the atmosphere. The direction of pollutant transport is a function of the prevailing winds.

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[7]Carl F. Fisher, loc. cit. Supplementary map sheets numbers 9-12 were used to determine the different soil types in the study area.

Wind speeds and calm periods influence the buildup of air pollution or lack of such. As wind speeds increase, dispersion of particulates is more rapid and generally lower pollution deposition levels result.[8]

To get an idea of the wind movement for the Southard area, an analysis of the prevailing wind directions on both a regional and local scale was conducted. Data were accumulated from first order weather stations surrounding Southard.

A summary of the prevailing monthly winds and average monthly wind speeds appears in Table IV-1. It can be seen that there is a strong south to south-southeast wind during the growing season (April-September).

In addition to a regional wind pattern, a local wind rose was constructed using wind data supplied by the U.S. Army Corps of Engineers at Canton Dam for the years 1963-69 (Figure IV-2). This proved to be fairly consistent with the regional wind pattern. In this case a predominant south to southeast wind existed, and a secondary prevailing wind from the north was also observed. Very small east-west components of the wind occurred. Based on this wind pattern, most of the pollution from the gypsum plant could be expected to be transported to the area north to northwest of the processing plant. Transport to the south would occur when the northerly winds prevailed. This is no doubt what happens, but the ultimate depositional pattern of the dust is subjected to the influence of other variables such as wind speed and topography.

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[8]James D. Williams and Norman G. Edmisten, An Air Resource Management Plan for the Nashville Metropolitan Area (Cincinnati: Public Health Service Bulletin No. 999-AP-18, 1965), p. 75.

TABLE IV-1

MONTHLY PREVAILING WINDS AND WIND SPEED AVERAGES (mph) FOR FIVE SELECTED FIRST ORDER WEATHER STATIONS, 1950-70

Weather Station	Month											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Oklahoma City, Oklahoma	N	N	SSE	SSE	SSE	SSE	SSE	SSE	SSE	S	S	SSE
	14.5	14.5	15.9	15.8	14.2	13.6	11.8	11.7	12.2	12.7	13.2	13.6
Tulsa, Oklahoma	S	N	S/SSE	S	S	S	S	SSE	S	S	S	S
	11.0	11.3	12.5	12.4	11.1	10.4	9.4	9.1	9.4	10.1	10.6	10.7
Wichita, Kansas	S	N	S	S	S	S	S	S	S	S	S	S
	12.9	13.3	14.9	15.0	13.6	13.4	11.6	11.6	12.0	12.6	12.6	12.5
Amarillo, Texas	SW	SW	SW	SW	S	S	S	S	S	SW	SW	SW
	12.9	13.9	15.2	15.0	14.6	14.1	12.2	11.4	12.6	12.8	12.8	12.9
Wichita Falls, Texas	S	N	S	S	SSE	SSE	S	S/SSE	SE	S	S	B
	11.2	11.5	13.0	13.1	11.3	11.9	10.9	10.2	10.2	10.3	11.0	10.9

Source: State Climatological Data for Kansas, Oklahoma, and Texas, 1950-70.

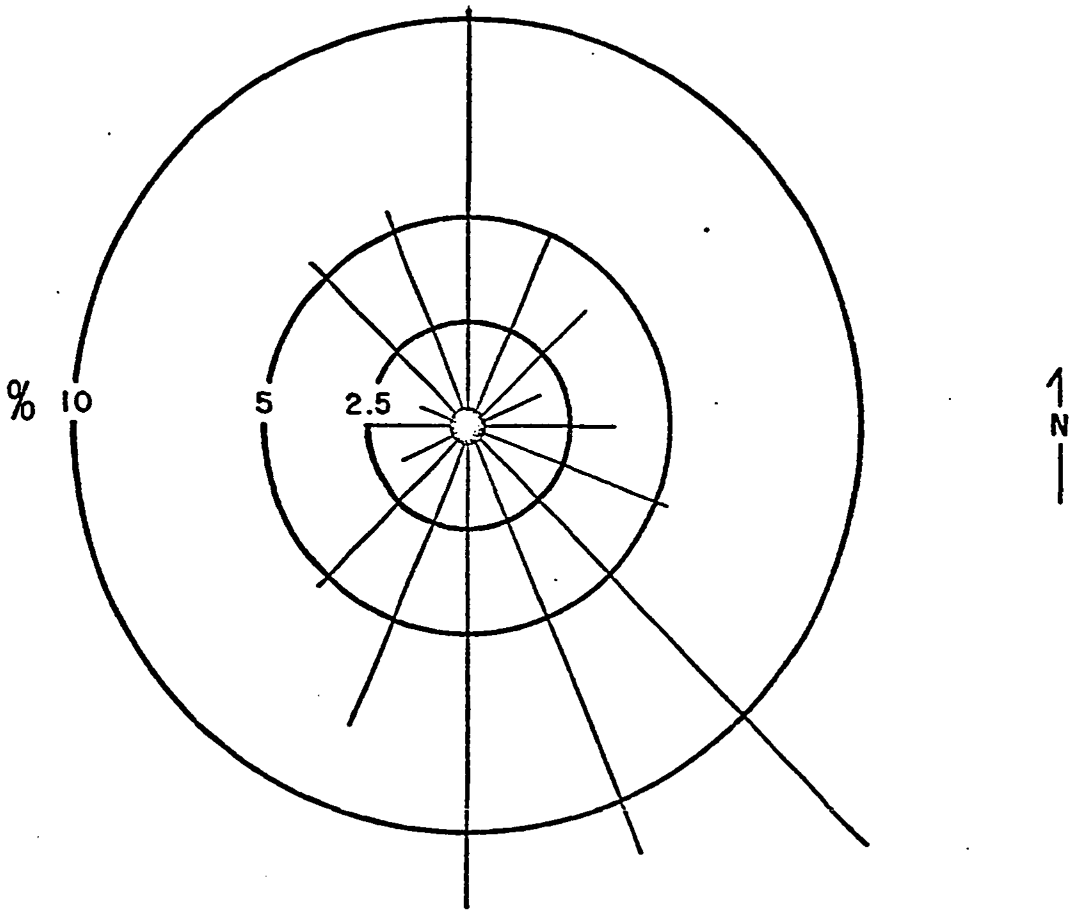

Figure IV-2. Wind rose for Canton Dam, Oklahoma, 1963-69. (Source: U.S. Army Corps of Engineers.)

Variations in the prevailing wind pattern can be induced by topographic variation. One such variation can be induced by a valley situation which may subtract from the component of the wind by channeling.[9] A steep-sided railroad cut such as the one in the study area may account for a certain amount of wind channeling, and thus a depositional pattern slightly different from the expected based on an analysis of prevailing winds only. This channeling serves also to concentrate the gypsum particulates and may increase the quantity deposited there.

Wind speeds exert a profound influence on the deposition rate of airborne particles. A study conducted in Nashville, Tennessee, by the United States Public Health Service indicated that average wind speeds of 8.6 miles per hour and greater helped disperse air pollution, while average speeds of 6.4 miles per hour and below led to severe air pollution buildup.[10]

Because of the importance of wind speeds in the depositional pattern, average speeds for each direction were computed for the area using the U.S. Army Corps of Engineers' data for Canton Dam. The results are presented in Table IV-2.

TABLE IV-2

Average Wind Speed for Direction, 1963-69

Direction	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Avg. Spd.	7	7	6	4	5	9	12	14	13	13	10	8	9	7	11	12

Source: U.S. Army Corps of Engineers, Canton Dam, Oklahoma

[9] Slade (ed.), _op. cit._, p. 27.

[10] Williams and Edmisten, _op. cit._, p. 75.

It must be pointed out that the average wind speeds for each direction as presented in Table IV-2 are not the same as average monthly wind speeds as presented in Table IV-1. Using the Nashville study as a basis for interpretation, the high wind speeds (12-14 miles per hour) that occur with the south to southeast winds would tend to disperse and dilute the airborne particulate matter which would result in a reduction in deposition in the area north to northwest of the processing plant. On the other hand, the relatively low wind speeds (6-7 miles per hour) associated with the north to northeast winds could lead to an increase in the particulate deposition in the area south to southwest of the processing plant. A hazard arising from the use of averages in interpreting the role of the wind in this study is overgeneralization; therefore, it is the author's intention here only to suggest a possible role of wind speed and direction in dispersing and diluting the pollution. A clearer picture of the influence of wind can only come about as a result of a more detailed analysis of this climatological variable in this area.

Precipitation

The rainfall which an area receives will largely determine the growth rate of the vegetation. Studies by Fritts have demonstrated that during drought years vegetation growth is reduced from that of normal precipitation years.[11]

For this study precipitation is also important from the standpoint of its ability to wash the accumulating dust off the leaves of the trees. In wet years, one could assume on the average a lower

[11] Harold C. Fritts, "Growth Rings of Trees: Their Correlation with Climate," Science 154 (1966): 973-979.

concentration of the gypsum dust on the leaves than in dry years because of this cleansing effect of the precipitation. In dry years there is less rainfall to wash the dust from the leaves so it accumulates and thus increases the reflectivity of the canopy and further prevents the necessary light waves from reaching the leaves to perform photosynthesis. This phenomenon, added to the stress of reduced soil moisture, presents a double problem for the vegetation.

Graphs were constructed using the data from the five first order weather stations and Canton Dam showing the rainfall pattern in the Southard area (Figure IV-3). On the average, the period 1951-55 was the driest of all five growth periods while the period 1956-60 was the wettest. The influence of the precipitation is reflected in the analysis of the growth pattern of the vegetation for the different periods.

In conclusion, the differences in wind speed and direction should create a pattern favoring gypsum deposition in an area south to southwest of the plant as a result of the low wind speeds accompanying the north to northeast winds. In addition, not all of the north to northeast winds occurred during the winter, or non-growing season. The Corps of Engineers data show that the wind blew from the north, north-northeast, and northeast a total of 220 days from April through September (the growing season) between 1963-69. This amounts to approximately 12 percent of the total period. The author does not mean to imply that the dust is not deposited in sufficient quantities in other parts of the study area; certainly this does occur. On the basis of the available data, there is an indication that deposition can indeed occur in the area roughly southwest of the processing plant during

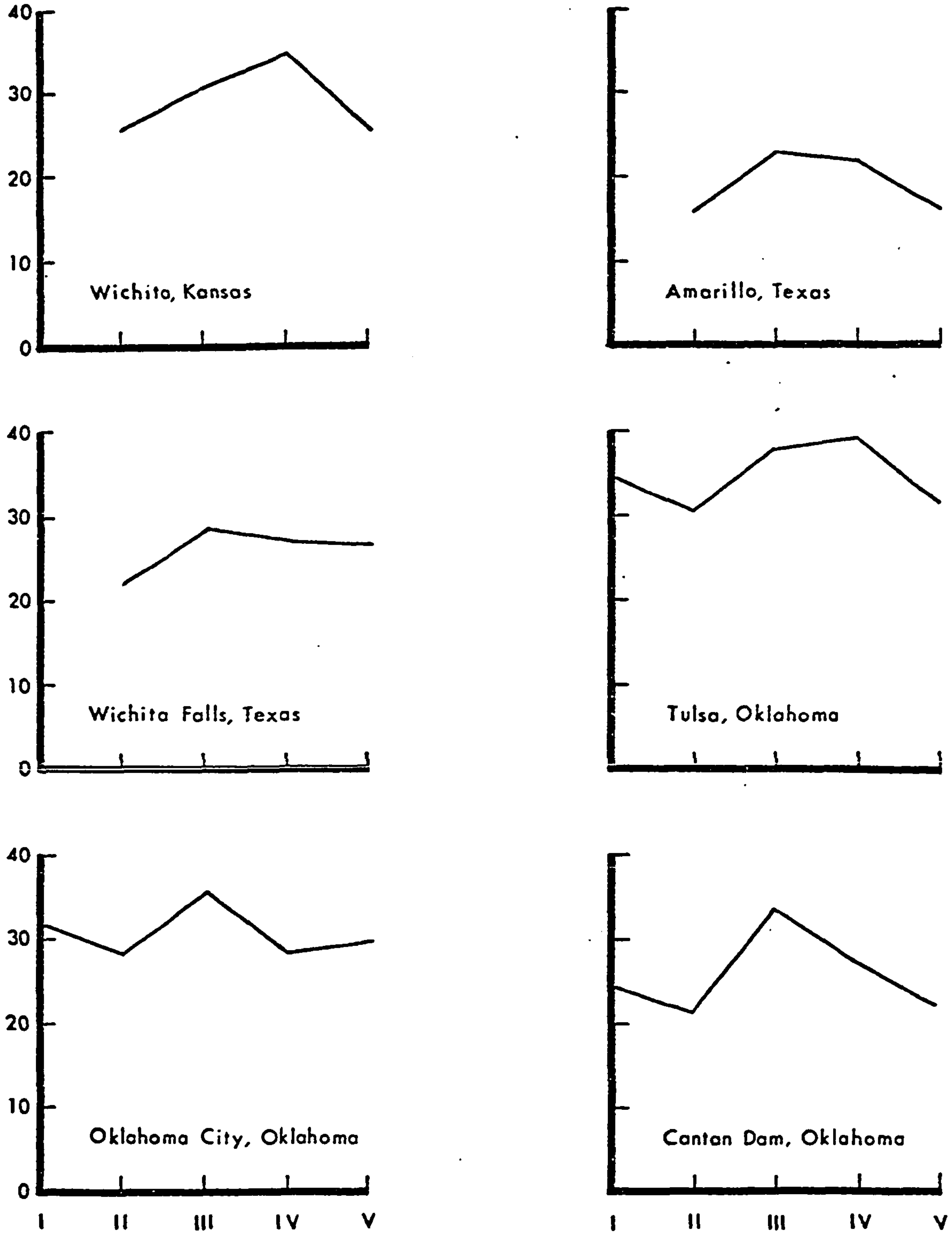

Figure IV-3. Average yearly rainfall for the assigned growth periods at six selected stations. (Source: State Climatological Data, 1946-70, and U.S. Army Corps of Engineers).

the growing season. The buildup of dust on the trees in this area during the growing season has the potential to reduce growth rate significantly.

The influence of the precipitation is seen in adding to the soil moisture bank and washing the dust from the leaves and thus into the soil.

Vegetation

In order to determine what represented below-average growth rates in the Southard area, it was necessary to establish the average growth rate for the trees living under normal conditions for this particular area. In order to do this a group of trees was randomly selected as a control group. The group was selected in specified areas six to seven miles west of the processing plant. The samples consisted of oaks (*Q. stelleta* and *Q. marilandica*) from areas of Nobscott fine sand and Pratt loamy fine sand soils. The sampling activity was conducted on areas of flat topography. In short, the environment of the control group was identical to that of the target population except that the control group was not exposed to gypsum dustfall.

The trees in the control group were processed in the same fashion as the others with respect to measurement and organization into specific growth periods. A total of 23 control samples was obtained (Appendix D). Averages and standard deviations were calculated for each growth period, with one standard deviation representing the upper and lower limits of average growth rate for each specific growth period (Table IV-3).

TABLE IV-3

Average Growth Rate and Standard Deviation
for Control Samples (cm)

Growth Rate	Year				
	1946-50	1951-55	1956-60	1961-65	1966-70
Average	1.36	1.25	1.42	1.28	1.05
St. Dev.	.54	.38	.60	.46	.42
Upper Limit	1.90	1.63	2.02	1.74	1.47
Lower Limit	.82	.87	.82	.82	.63

Source: Author's calculations.

In computing the trend surface analysis on the sampling population, the value of the lower standard deviation limit was designated as a reference contour for each respective growth period. Any value equal to or less than the reference contour was considered to be representative of below-average growth. Any such area would be indicated on the computer print-out by special symbolization.

A contour interval was established by taking the difference between the lower and upper standard deviation limits. Any value equal to or greater than the reference contour plus the contour interval would be representative of vegetation having a greater than average growth rate, and such areas would also appear on the print-out map as special symbolization.

After conducting a trend surface analysis on each growth period, it was then necessary to determine which of the six degrees of trend surface best explained the relationship between vegetation growth and distance from the processing plant. To evaluate the strength of each fitted surface, an analysis of variance testing procedure described by Krumbein and Graybill was used.[12] For each growth period, the variance explained by the linear equation was divided by the degrees of freedom (2). The unexplained variance (the deviations from the linear) was also divided by their respective degrees of freedom (44).[13] This procedure yielded a mean square for both the explained and unexplained variance. An F value was then calculated from these and reference made to an F table to determine the significance of the value.

Testing the quadratic surface involved subtracting the explained variance of the linear surface from the explained variance of the quadratic surface and assigning the difference (the increase in explained variance) to test the significance of the quadratic equation. In addition, three degrees of freedom of the 44 associated with the linear deviations were assigned to the surface, leaving 41 for the deviations. Again, an F value was calculated and checked for significance. The procedure was continued through the sixth degree fit. After testing each growth period, the degree of fit that tested out as the most significant (the one that established the strongest surface fit) was selected for interpretation and analysis. A complete set of the tests is presented in Appendix E.

1946-50

The fifth degree, or quintic, polynomial equation was selected as the one that best explained the surface fit for the 1946-50

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[12] Krumbein and Graybill, loc. cit.

[13] There were a total of 47 plotted points, giving a total of 46 degrees of freedom. If the two degrees of freedom are taken for the explained variance as a result of the linear equation, then that leaves 44 degrees of freedom for the unexplained variance.

growth period.[14] However, the confidence level for this equation was only 50 percent, which indicates a very weak trend. It was mentioned earlier in this study that little, if any, significance was expected to be associated with this period because of the relatively low production values associated with the processing plant at this time.

The spatial relationship between vegetation growth and distance from the plant for this growth period are depicted graphically in Figure IV-4. Error measures are given in Table IV-4. Although the values associated with the fifth degree fit for this period are not significant to any respectable degree because of the low confidence level, an analysis of the pattern is nevertheless warranted.

There is the existence of an area of less than average growth rate just to the southwest of the processing plant and nowhere else. It is suggested here that the location of the affected vegetation, however insignificant the trend is, may be a function of the north to northeast winds with the low wind speeds.

1951-55

The equation with the strongest explanation of trend for the 1951-55 growth period is the fourth degree (quartic) equation. This fit had an associated confidence level of 75 percent, which represents a substantial increase over the significance of the 1946-50 trend. Figure IV-5 shows the relationship between the vegetation growth and distance from the plant. Compared to the 1946-50 growth period, this period has a relatively large area associated with reduced vegetation growth (Figure IV-6). This is attributed to two factors: (1) the

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[14]Equations selected on the basis of best fit for each of the growth periods are given in Appendix F.

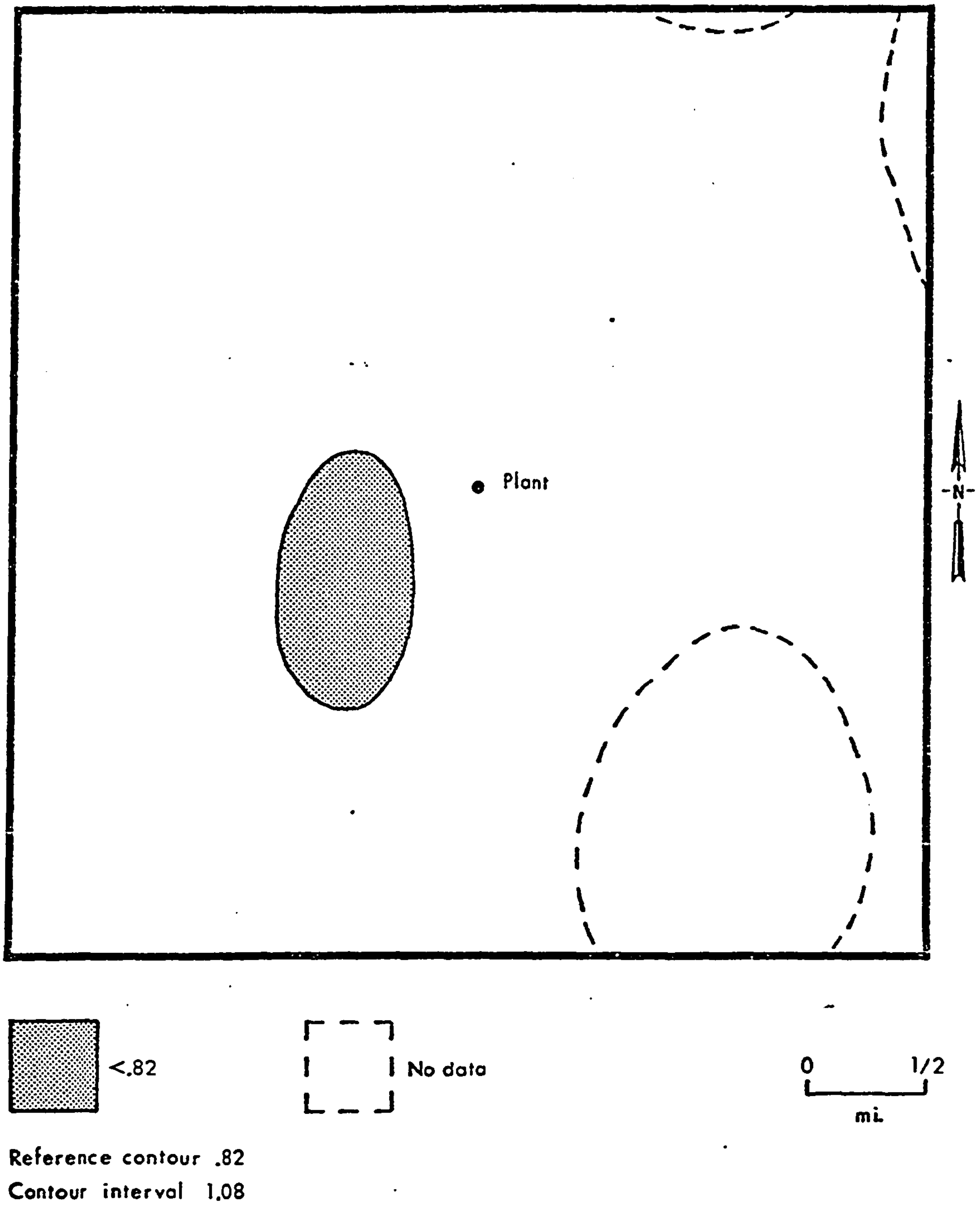

Figure IV-4. Contoured fifth degree surface for the 1946-50 growth period. (Source: Author's calculations.)

TABLE IV-4

Error Measures (cm): 1946-50

Measure	cm
Standard Deviation	.31
Explained Variance	2.67
Unexplained Variance	4.32
Total Variance	6.98
Coefficient of Determination (R^2)	.38
Correlation Coefficient (R)	.62

Source: Author's calculations.

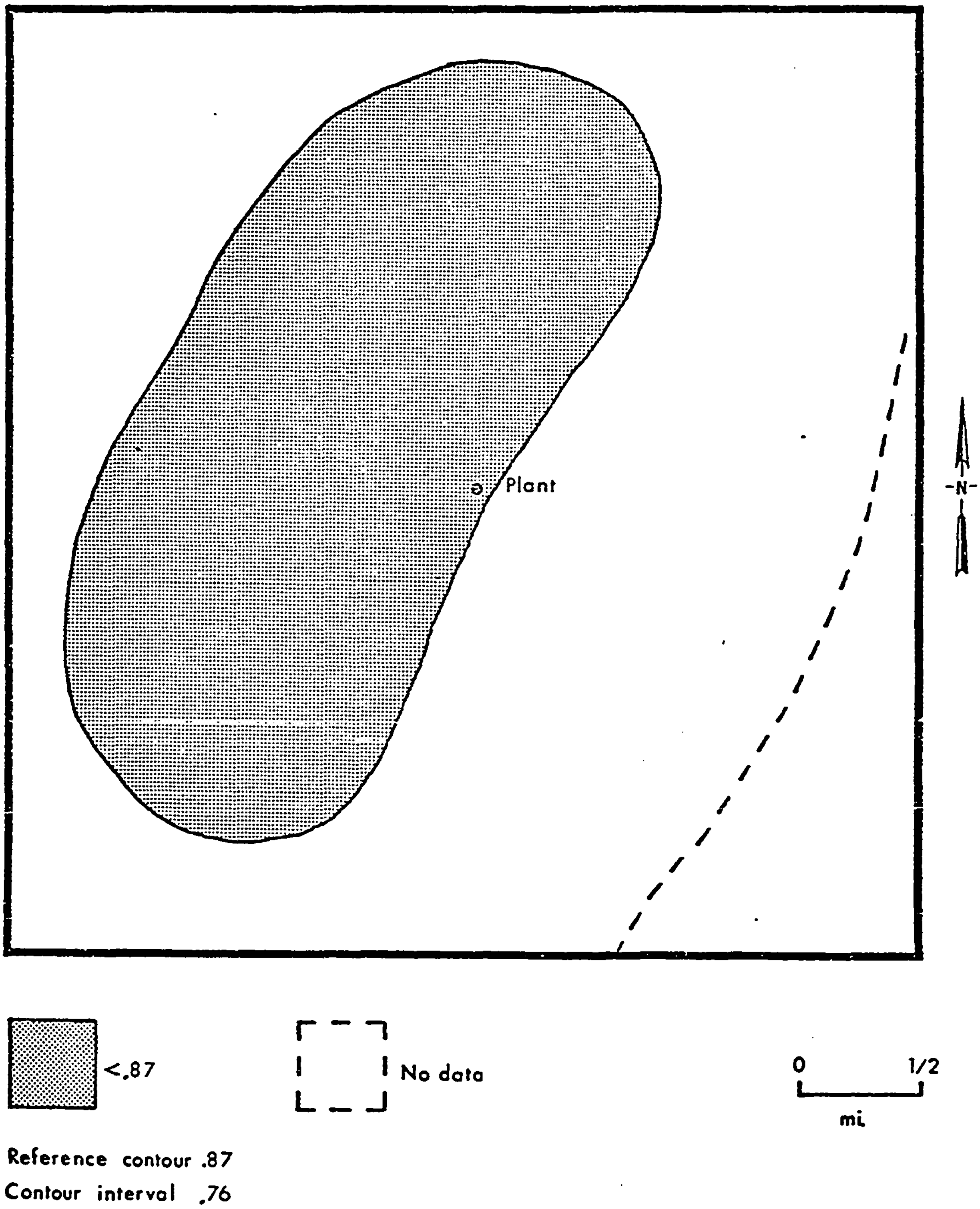

Figure IV-5. Contoured fourth degree surface for the 1951-55 growth period. (Source: Author's calculations.)

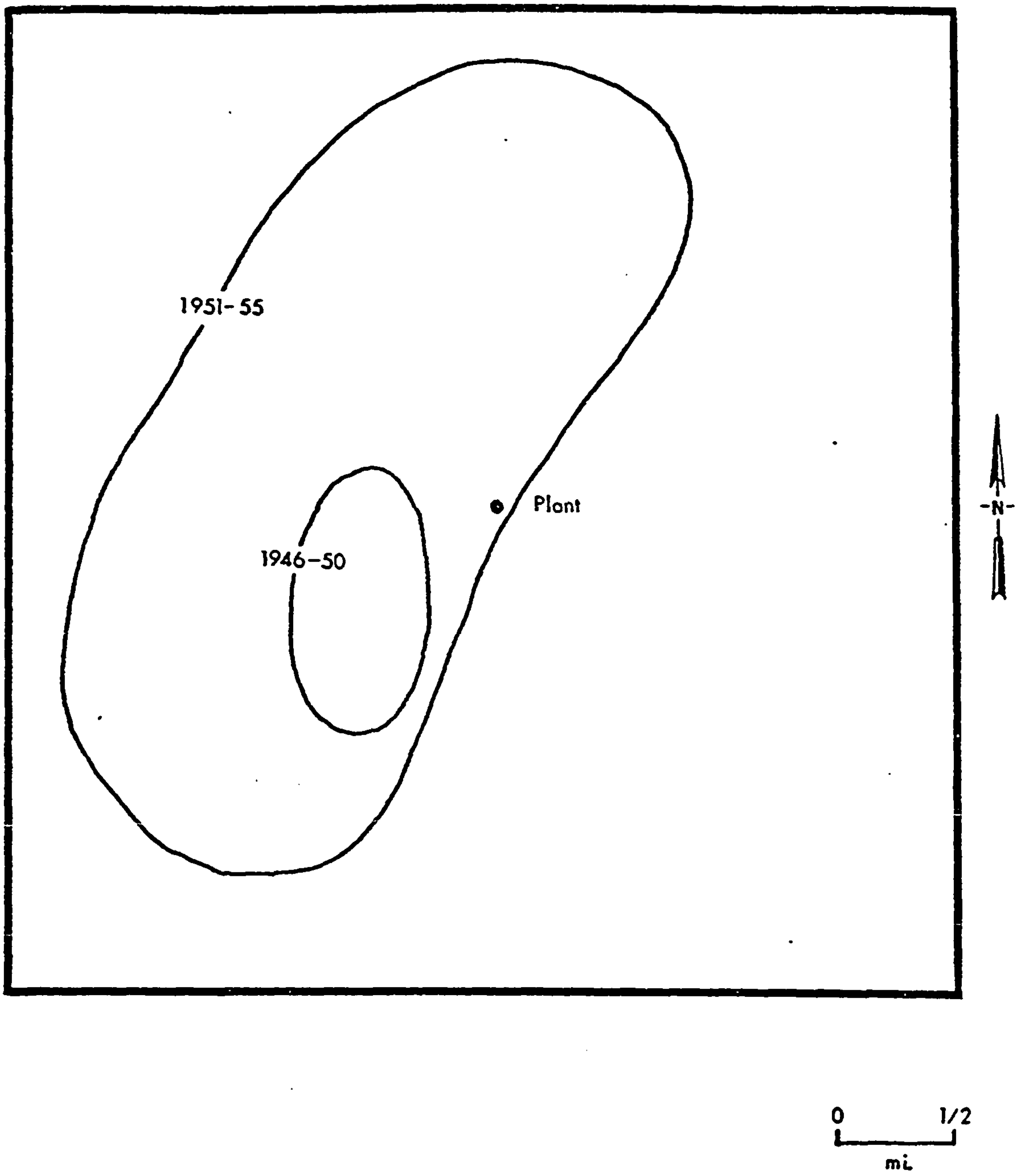

Figure IV-6. Comparison of areas of reduced growth rate for the 1946-50 and 1951-55 periods.

gypsum plant increased production from an average of 233,575 tons per year for the 1946-50 growth period to an average of 289,636 tons per year for the 1951-55 growth period (an increase of an average of 56,061 tons per year; (2) more important, perhaps, is the influence of the reduced precipitation during this growth period down from an average of 22.68 inches per year at Canton Dam for 1946-50 to an average of 21.73 inches per year for 1951-55. During the early 1950's the Great Plains, and particularly this part of Oklahoma, were subjected to a severe drought. The drought is reflected in the low precipitation values for the surrounding areas. The dual stress provided by the increase in gypsum processing and the reduced rainfall could have easily led to the increased extent of impact on the vegetation. Table IV-5 gives the error measures associated with the quartic fit of the 1951-55 growth period.

TABLE IV-5

Error Measures (cm): 1951-55

Measure	cm
Standard Deviation	.20
Explained Variance	1.02
Unexplained Variance	1.77
Total Variance	2.79
Coefficient of Determination (R^2)	.36
Correlation Coefficient (R)	.60

Source: Author's calculations.

1956-60

The best fit for the 1956-60 growth period was accompanied by the fifth degree (quintic) trend surface. Like the 1951-55 period, this period tested out to a 75 percent significance level. Figure IV-7 graphically portrays the area of affected growth rate. Like the 1946-50 pattern, most of the below-average growth appears in an area southwest of the processing plant. The 1956-60 pattern exhibits an affected area greater than that of the 1946-50 period, but much less than that of the 1951-55 period (Figure IV-8). The level of gypsum processing remained approximately the same for both the 1951-55 and 1956-60 growth periods, so it can be assumed that the environment was exposed to approximately the same amount of dust from the stack. However, the role of precipitation becomes important here. Rainfall in the surrounding area increased substantially in this period over the drought period of the early fifties. At Canton Dam the increase was from an average of 21.73 inches per year for 1951-55 to an average of 33.07 inches per year for 1956-66, an increase of an average of 11.34 inches per year. Had the precipitation conditions remained the same for the two growth periods the pattern of affected vegetation would be expected to be about the same. In this case, however, the rainfall probably had the effect of adding to the soil moisture bank in addition to washing the accumulating dust from the leaf canopy permitting more photosynthetic activity to take place.

Another significant event occurring during this time period that likely influenced the reduction in affected areas was the installation of dust control equipment in 1957.[15] At this early date the effectiveness of the air pollution control device is questionable,

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[15] J. R. Baker, personal communication, August 18, 1971. In correspondence with the author, J. R. Baker, works manager for the United States Gypsum Company processing plant at Southard, noted that dust control equipment was installed in 1957, 1965, 1968, and 1969.

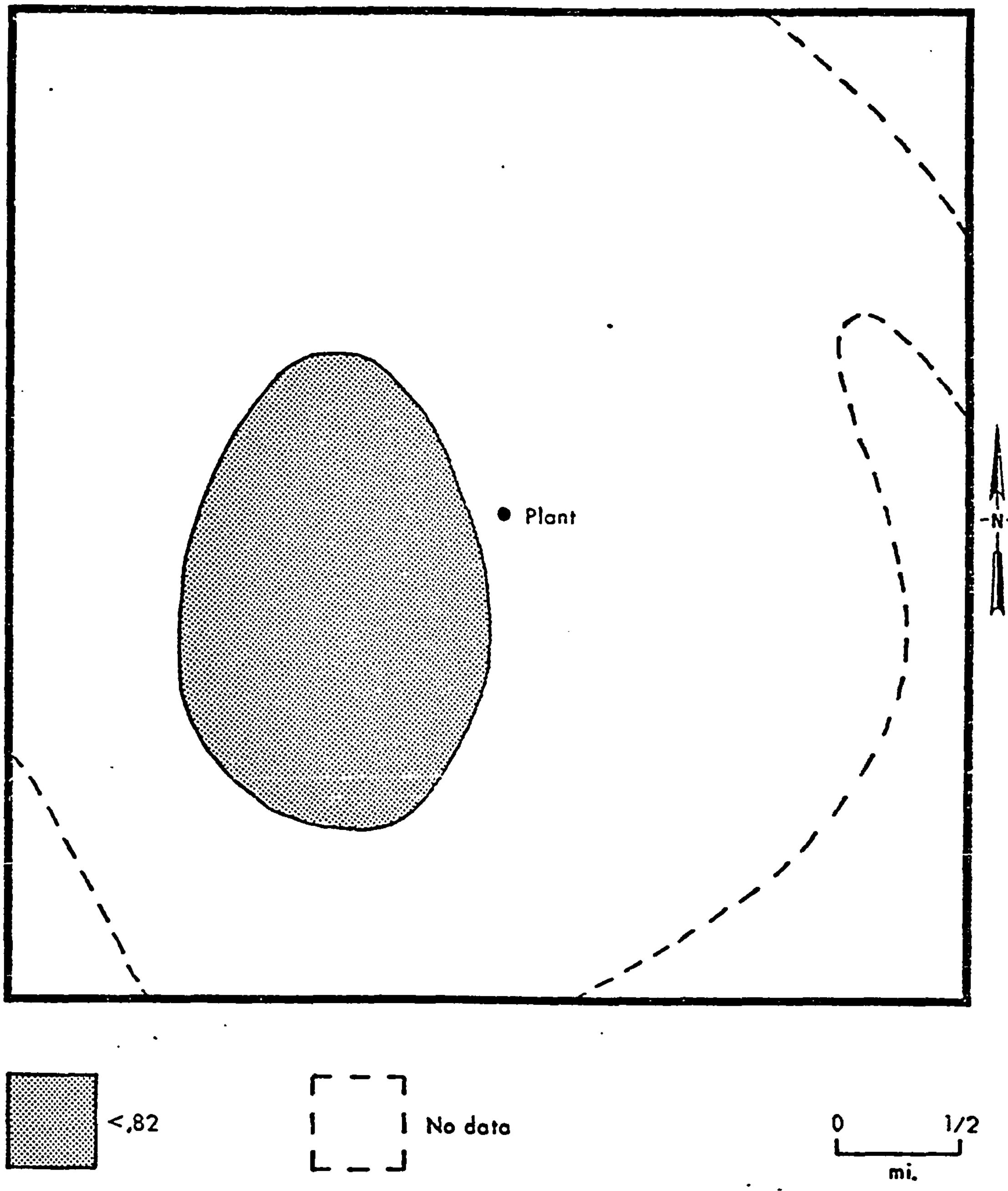

Figure IV-7. Contoured fifth degree trend surface for the 1956-60 growth period. (Source: Author's calculations.)

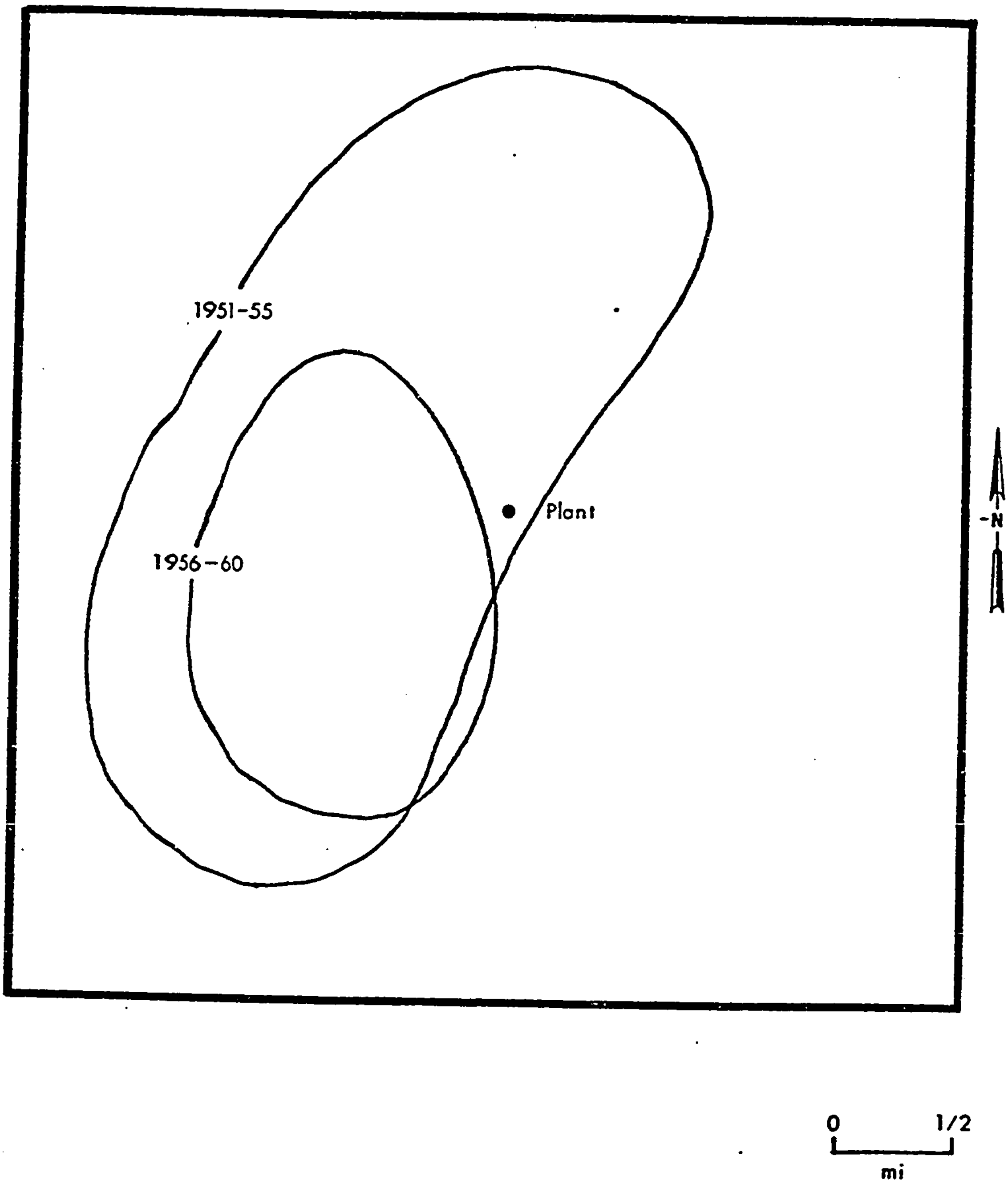

Figure IV-8. Comparison of areas of reduced growth rate for the 1951-55 and 1956-60 periods.

and its effect on vegetation growth rate via controlling dust emission is unknown.

The error measures associated with the fifth degree fit for the 1956-60 growth period are presented in Table IV-6.

TABLE IV-6

Error Measures (cm): 1956-60

Measure	cm
Standard Deviation	.26
Explained Variance	2.39
Unexplained Variance	3.02
Total Variance	5.41
Coefficient of Determination (R^2)	.44
Correlation Coefficient (R)	.67

Source: Author's calculations.

1961-65

In the period 1961-65 the processing plant increased production to an average of 450,328 tons per year, an increase of 161,811 tons per year over the 1956-60 period. Such an increase would be expected to have a profound effect on the area vegetation based on the previous analyses. Accompanying this increase in gypsum production, this period was associated with a decrease in average yearly precipitation. Canton Dam averaged 27.73 inches per year for 1961-65 compared to an average of 33.07 inches per year for the 1956-60 period. However, on inspection of the trend surface map, the spatial distribution of the area of affected vegetation (Figure IV-9) is not much different from the pattern displayed by the distribution of the preceding growth period (Figure IV-10). This is attributed to the fact that the full

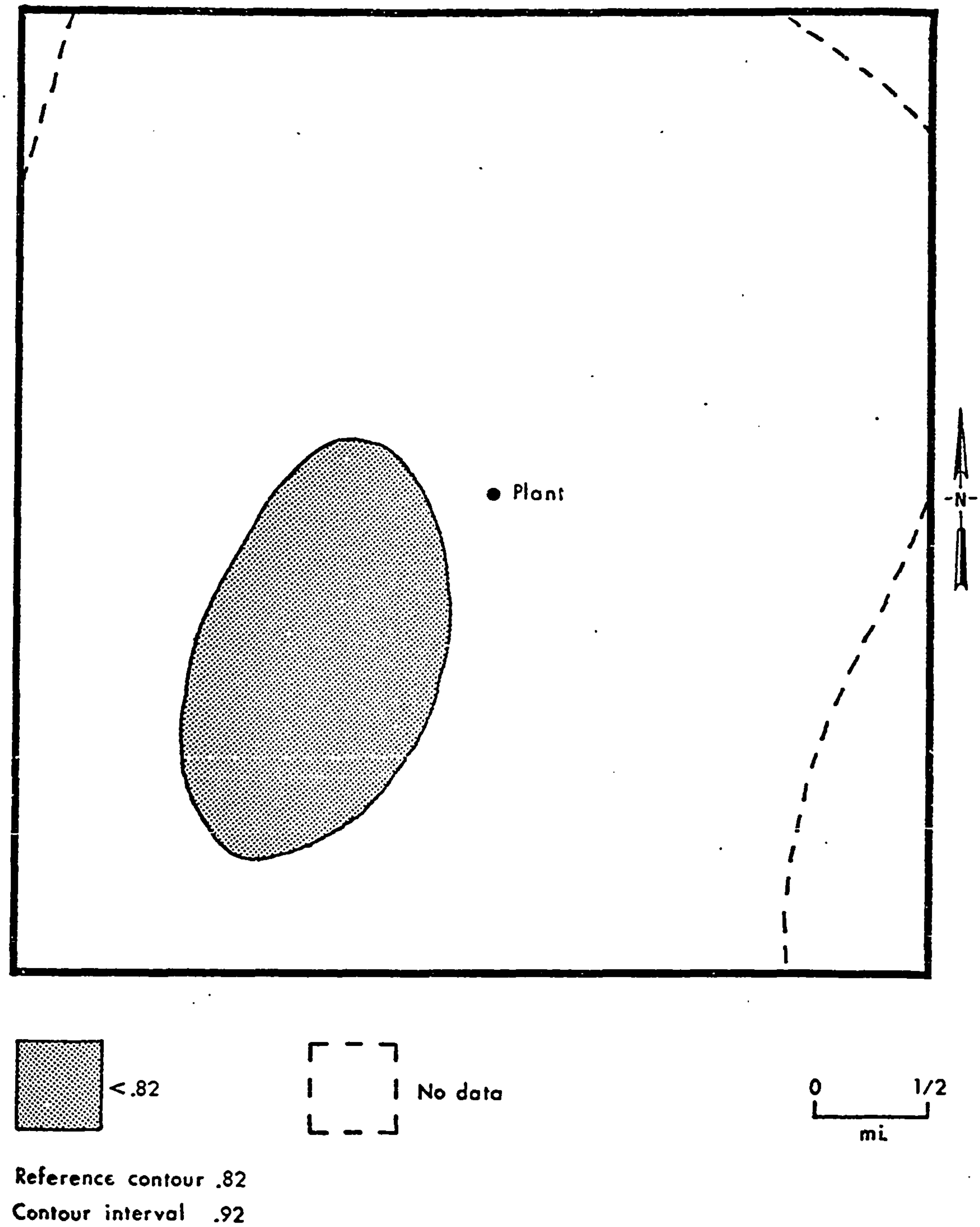

Figure IV-9. Contoured fourth degree trend surface for the 1961-65 growth period. (Source: Author's calculations.)

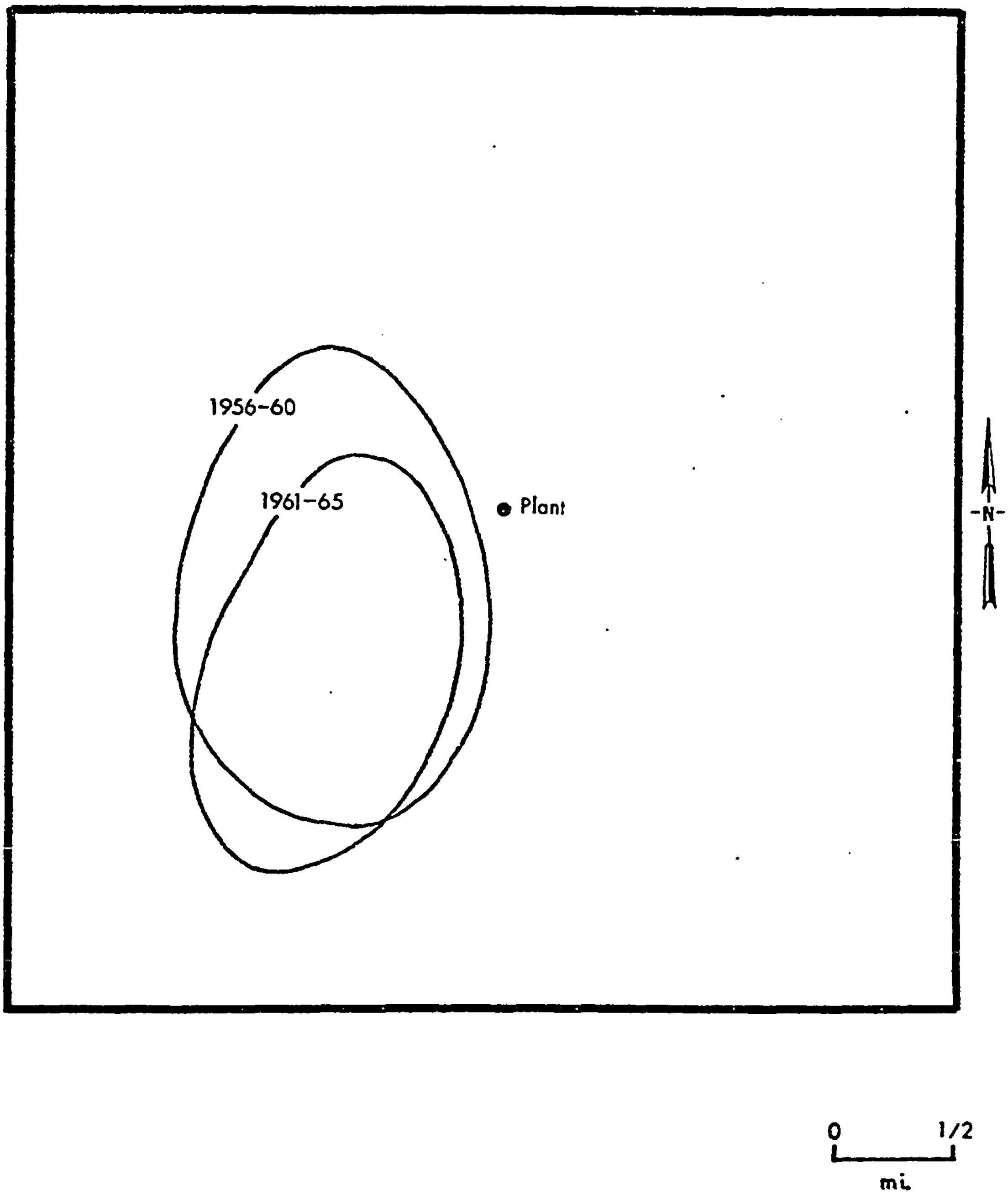

Figure IV-10. Comparison of areas of reduced growth rate for the 1956-60 and 1961-65 periods.

impact of added dust controls was not felt until the 1961-65 period. These controls, initially installed in 1957, would account for at least three years of that growth period with a certain amount of dust control, but not the entire period. The effectiveness of the controls during the 1961-65 period, including a 1965 installation, likely offset the combined effect of the increase in production and the decrease in precipitation.

Again the affected area is located primarily to the southwest of the processing plant. Some consistency in the pattern of the affected area has been established.

The fourth degree (quartic) fit for the 1961-65 growth period tested out to the 97.5 percent significance level. The values associated with the quartic fit are given in Table IV-7.

TABLE IV-7

Error Measures (cm): 1961-65

Measure	cm
Standard Deviation	.24
Explained Variance	2.68
Unexplained Variance	2.61
Total Variance	5.31
Coefficient of Determination (R^2)	.50
Correlation Coefficient (R)	.71

Source: Author's calculations.

1966-70

The growth period for 1966-70 had the smallest total area of affected vegetation growth compared to all other growth periods (Figure IV-11). The average gypsum production level for this period was 478,068 tons per year, representing an increase of 27,740 tons

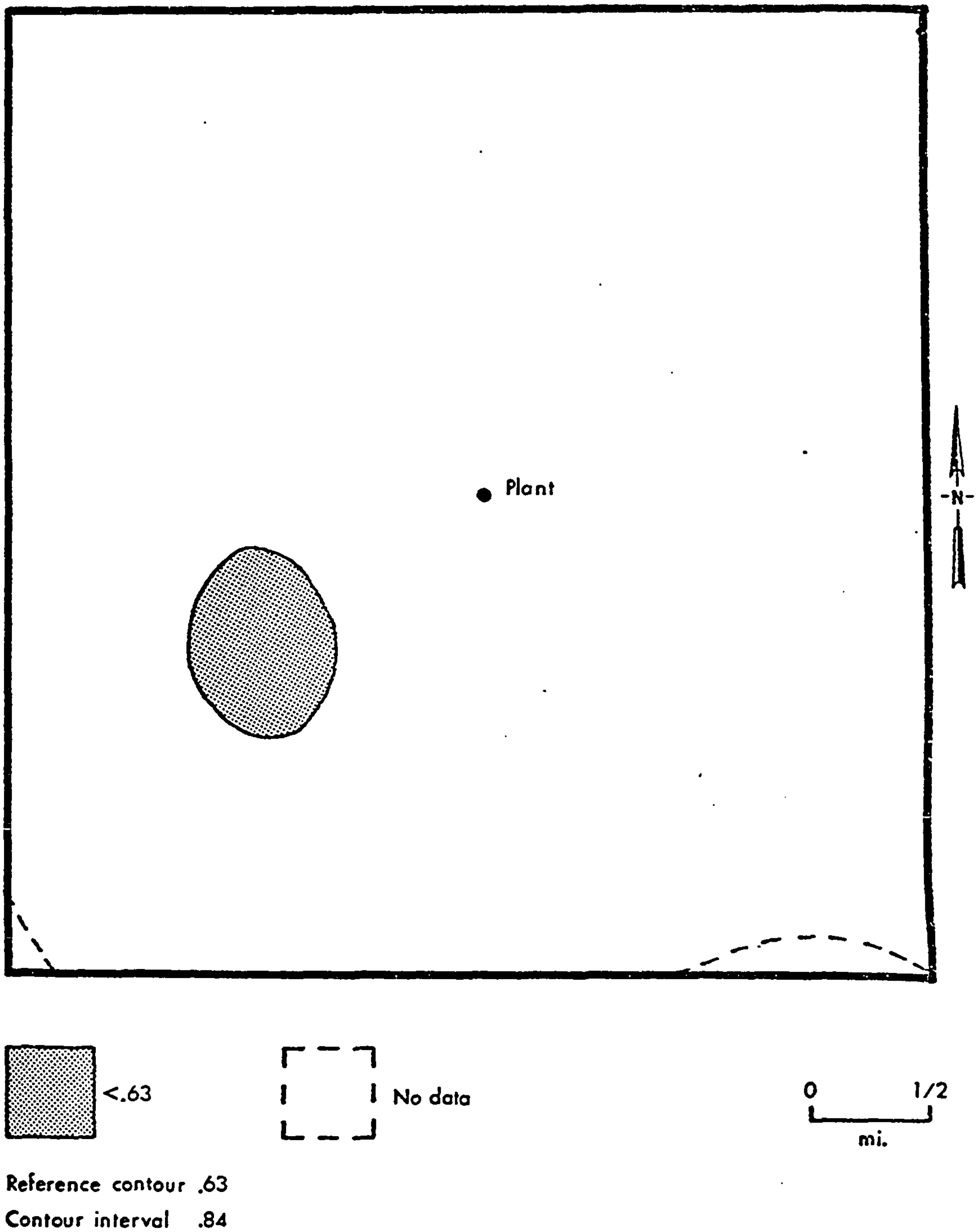

Figure IV-11. Contoured third degree trend surface for the 1966-70 growth period. (Source: Author's calculations.)

per year over the 1961-65 growth period. Precipitation values for Canton Dam for this period were down from the 1961-65 period, averaging 22.89 inches per year compared to an average of 27.73 inches per year for the previous period. The environmental condition is much like the 1951-55 growth period where the production level is high and the precipitation is low. There was only about one inch difference in the average yearly precipitation for the drought period of 1951-55 and the 1966-70 period. Normally, this would yield a relatively great area of affected vegetation growth based on the 1951-55 analysis. However, during this period additional dust controls were installed in 1968 and 1969. In addition, the 1965 installation, while not having full impact on the 1961-65 growth period, was in operation during the entire 1966-70 period. It is also assumed that from the first installation in 1957 to the last in 1969, the effectiveness of the dust controls increased as a result of more stringent federal control standards. Therefore, it appears that for the 1966-70 growth period a significant effect of the dust control mechanisms is added to reduce the effluent leaving the stack at the processing plant. The small total area of affected vegetation is an indication of the effectiveness of the air pollution controls given the production level and the environmental conditions. The affected area of vegetation growth is once more located in an area to the southwest of the processing plant.

The equation selected for the 1966-70 interpretation was a third degree (cubic) fit with a 97.5 percent confidence level. Associated error measures are given in Table IV-8.

For comparison, a composite map of the affected growth areas for each growth period is presented in Figure IV-12. All of the

TABLE IV-8

Error Measures (cm): 1966-70

Measure	cm
Standard Deviation	.25
Explained Variance	1.57
Unexplained Variance	2.95
Total Variance	4.53
Coefficient of Determination (R^2)	.34
Correlation Coefficient (R)	.59

Source: Author's calculations.

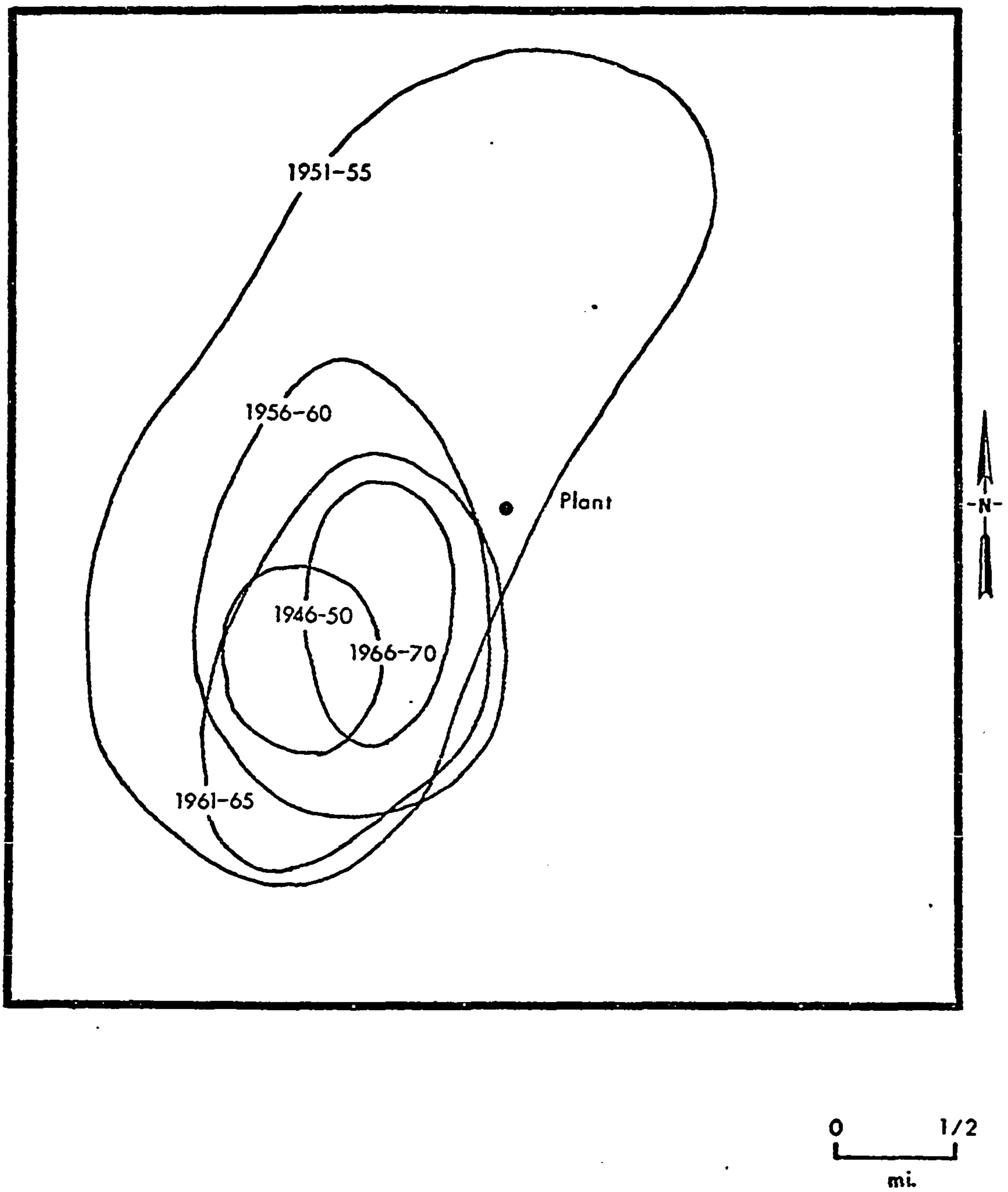

Figure IV-12. Composite map of the areas of growth reduction for the five growth periods.

enclosed circles represent regions of growth inhibition. In no case at all were there any regions of accelerated vegetation growth rate in the study area.

Discussion

The affected vegetation growth rate patterns warrant discussion. The analyses indicate there is a curvilinear relationship between industrial gypsum dust fallout and the spatial variation in the growth rate of vegetation in the vicinity of the processing plant, thus establishing support for acceptance of the substantive hypothesis.

The effect of the dust is manifested by a retardation of the growth rate among the trees which are exposed to the highest concentrations of dust deposition. The retarded growth rate results, in the author's opinion, from the accumulation of the powder-like gypsum dust on the leaf canopy which reflects a significant amount of the solar radiation responsible for photosynthetic activity. A study by Doraiswamy concerning the use of white kaolinite dust application on soybeans revealed an altered reflection characteristic of the plants without directly affecting the stomatal mechanisms.[16] The light-colored dust reflected as much as 58.8 percent of the incident solar radiation, and the reflective coating was responsible for altering normal photosynthetic activity. As a result there was a definite decrease in water use by the treated crop and growth was described as inhibited. Another reflective treatment involving white acrylic paint on tomatoes and citrus trees resulted in lower yields and

[16] Paul C. Doraiswamy, Energy Balance and Spectral Properties of a Reflectorized Soybean Canopy (Lincoln: University of Nebraska College of Agriculture, 1971), 189 pp.

reduced fruit size for the treated plants.[17] A decrease in transpiration, attributed to the reflection of visible light waves, was often accompanied by detrimental effects on plant growth. Some clogging of the stomata by the dust may also occur, but this is regarded as being of secondary significance because of the extremely small size of the stomata and the fact that most of the stomata are located on the underside of the leaf and are not exposed to direct dust fallout. A microscopic examination of some collected samples by the author revealed no stomatal clogging by the gypsum dust.

There is a quasi-elliptical pattern associated with the affected areas which does not display the strict concentricity and circularity detailed in the theoretical model. This is probably due to three reasons:

1. The absence of a beneficial effect of gypsum dust. There is no indication of any significant accelerated growth rate among the sampled vegetation. The absence of a beneficial effect eliminates the presence of one of the zones enclosed by concentric rings in the model. The area under investigation is composed of vegetation that is growing either at an average growth rate or a below-average growth rate, the latter as a result of the effect of the industrial gypsum dust fallout. A beneficial effect of gypsum dust can and does result from a relatively heavy application of the dust to the soil followed by mechanical mixing. This does not occur in the study area. Much of the dustfall in the study area lands on the leaf canopy and

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[17] C. J. Gerard, Influence of Transpiration Suppresants, Sprinkler Irrigation and Moisture Levels on Transpiration and Evapotranspiration (Technical Report No. 27, Water Resources Institute, Texas A and M University, 1970), 101 pp.

apparently does not reach the ground in significant proportions at any one time. It is doubtful that this dust is accumulated on the ground to any great extent. Much of the gypsum is no doubt leached through the soil and lost to the vegetation. Buckman and Brady note that gypsum is soluble in water and is quickly removed if there is adequate rainfall.[18] Some of the gypsum is probably carried away in surface runoff. The beneficial effect of gypsum dust on vegetation in this area suggested by Jameson and Schiel must be explained away as the result of faulty sampling procedures.

2. The prevailing wind and wind speeds. For the most part, the patterns of affected vegetation for the five growth periods exhibit a consistency in location in an area southwest of the processing plant, although some deviation from this is observed in the 1951-55 pattern. This predominant pattern is interpreted as being the result of the influence of the north to northeast winds and the associated low wind speeds (six to seven miles per hour) which are conducive to air pollution buildup. The higher wind speeds (12-14 miles per hour) associated with the prevailing south to southeast winds apparently disperse and dilute the dust to the point where the amount falling on the leaf canopy has little or no growth-inhibiting effect.

The displacement of the affected area with respect to the emission source also warrants discussion. The affected areas for each of the growth periods are not located in such a manner that the emission source is at the center of the area as depicted in the theoretical model. For instance, the center of the 1966-70 affected area is

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[18]Buckman and Brady, op. cit., p. 277.

approximately one mile from the emission source. This distribution does not conform to that of the estimated relationship between vegetation growth rate and distance from the emission source of the dust (Figure I-2). The pattern is more like the one depicted in Figure IV-13. The reason for this may be a result of the fact that the mean concentrations of pollution (arising from a given source) at the ground level are generally some distance downwind from the source.[19] Figure IV-14 shows a typical pattern of air pollution deposition beneath a plume axis. The downwind distance of the macimum concentration of the air pollution is a function of wind speed, particle size, and atmospheric stability. The more stable the atmosphere, the greater the downwind distance to the maximum concentration.

An area of reduced growth rate can also occur as a result of a localized soil nutrition deficiency. In a study of bottomland forests in Oklahoma, Rice found in most cases the forests which occurred in areas that were low in fertility had low basal areas and were stunted in appearance. Rice found a high correlation between basal area and total nitrogen at the 18-24 inch level where there was normal precipitation.[20] Wilde, in a study of Wisconsin forest plantations, discovered an intimate correlation between physical and chemical properties of soils and the growth of trees.[21]

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[19] William F. Lowry, Weather and Life: An Introduction to Biometeorology (New York: Academic Press, 1967), p. 283.

[20] Elroy L. Rice, "Bottomland Forests of Oklahoma," Ecology, 46 (1965): 708-714.

[21] S. A. Wilde, "Soils and Forest Growth: Their Relationship in Terms of Regression Analysis," Bioscience, 20 (1970): 101-102, 108.

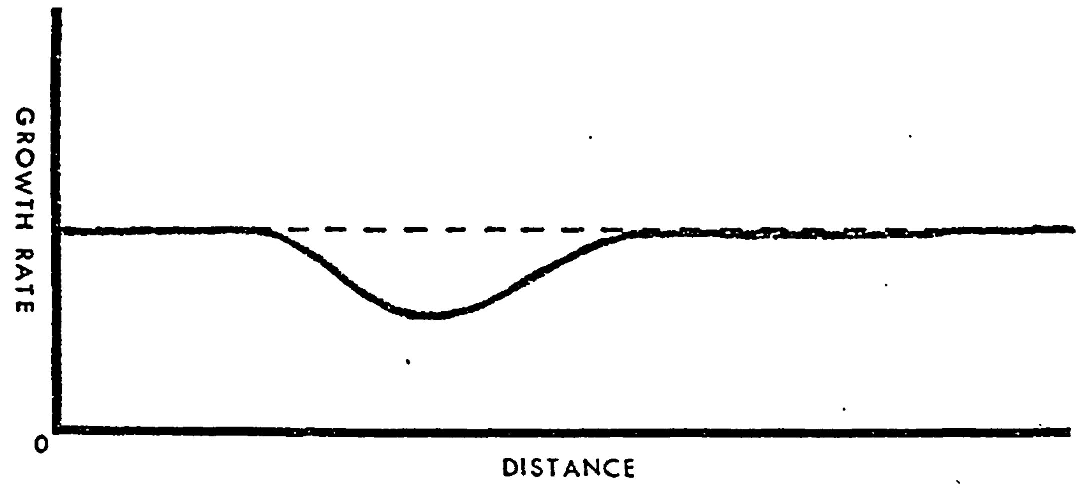

Figure IV-13. Relationship between area of reduced growth rate and distance from the plant.

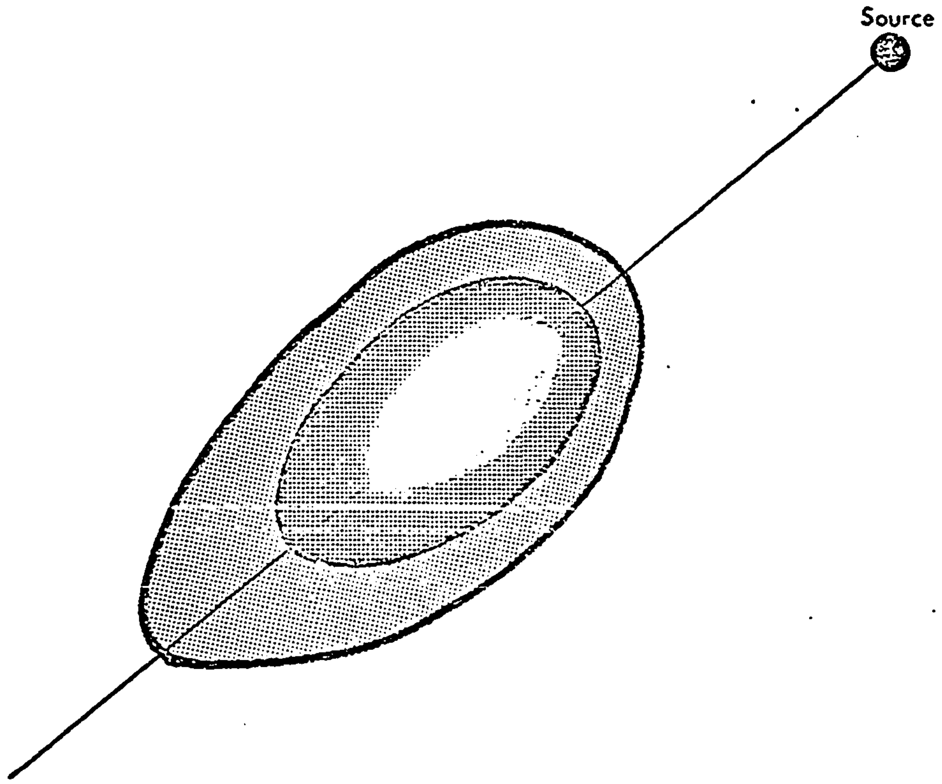

Figure IV-14. Typical ground level pattern of air pollution deposition beneath an air pollution plume. (From Lowry, Weather and Life: An Introduction to Biometeorology.)

While the author's main contention is that the region of reduced growth rate is a result of the air pollution, the possibility of an influence of localized nutrition deficiency is not ruled out. In the initial phase of this research, soil samples were obtained from the 0-6 inch and 18-24 inch level. The soils were analyzed with a LaMotte Sth-10 soil kit for humus, pH, nitrogen, phosphorus, potash, and calcium. All elements demonstrated a marked consistency; thus, soil sampling was discontinued and no samples were taken from the region of reduced growth.

3. Topography. An effect of topography, possibly the channeling influence exerted by the railroad depression, may be significant in affecting the path of the airborne gypsum dust.

There is nothing in the physical characteristics of the areas of affected vegetation that would indicate that an inhibited growth rate could exist there under normal conditions. All of the tree samples taken from these areas were oaks and the study area was dominated by Nobscott fine sand and Pratt loamy fine sand. Topographically speaking, the railroad depression represents the only significant variation in relief besides the quarries. Thus, the presence of vegetation exhibiting a growth inhibition is attributed to the influence of the airborne gypsum dust fallout, which is a function of distance from the emission source, climatology, and topography.

CHAPTER V

SUMMARY

Human activity and the natural environment can be compatible, and at times even complementary. More often than not, however, the opposite is true. Much of the environmental deterioration witnessed for the last one hundred years has occurred through the guise of progress with little concern for the final and total effect of this activity on the landscape. Rene Dubos pointed out:[1]

> Each particular place is a continuously evolving expression of a highly complex set of forces--inanimate and living--which becomes integrated into a . . . whole. Man is one of these forces, and probably the most influential. His interventions can be creative and lastingly successful if the changes he introduces are compatible with the intrinsic attributes of the natural system he tries to shape. The reason we are now desecrating nature is not because we use it to our own ends, but because we commonly manipulate it without respect for the spirit of place.

Aldo Leopold, the noted conservationist, predicted similar consequences because human beings lacked what he termed a "land ethic."[2] Philip Ackerman stated that:[3]

> The assumption is made that cultural processes now are major forces altering the continually changing earth space content,

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[1]Rene Dubos, A God Within (New York: Charles Scriveners and Sons, 1972), 362 pp.

[2]Aldo Leopold, A Sand County Almanac (New York: Ballantine Books, 1966), 295 pp.

[3]Phillip Ackerman, Geography as a Fundamental Research Discipline (Chicago: University of Chicago Department of Geography Research Paper, 1958), pp. 21-22.

> and must accordingly occupy significant space in geographical research. In the nineteenth century geography occupied itself with space content and still reflects reality on a large part of the earth's land surface. On the other hand, fundamental geographical research in the mid-twentieth century must include cultural processes as a major problem because of the accelerated spread of forceful cultural changes in the last 150 years.

The culture-associated process affecting the landscape with regard to this study is technological development. The imposition of the United States Gypsum Company processing plant on the rural environment at Southard is a direct result of the culture-associated process. Culture demands the product that the gypsum company provides, i.e., wallboard for construction purposes. In providing this product there can be, and usually is, a cost to the environment. The extent and ultimate limit of this cost is a function of what is done with the available technology manipulated by a supply and demand society. More important, however, the utilization of certain technological efficiency resulting from environmental quality considerations has minimized the potentially harmful ecological effects of the industrial activity.

This paper presents an inquiry into an air pollution problem involving the relationship between airborne gypsum dust and the growth rate of vegetation. Pollution of the atmosphere is merely one issue in the rapidly growing field of environmental studies. This study has indicated that gypsum dust pollution can have adverse effects on vegetation with regard to growth rate, but it has also pointed out that technological improvement in the form of dust control devices can reduce the total impact of the dust pollution on the environment.

The objective of this study was to determine what relationship existed between airborne gypsum dust and vegetation, and to define the degree and limits of any effect. In order to determine the relationship, the research focused on several facets pertaining to the specific problem: gypsum production, pedology, climatology, topography, and vegetation growth rate.

Chapter II was concerned with the organization of the research. In order to detail the relationship between the dust and the vegetation and formalize the approach to the study, a theoretical model was constructed with an associated set of assumptions.

Chapter III explains the rationale for the selection of the study area, the details concerning the sampling design and the collection process, and the statistical analysis technique.

The analysis (Chapter IV) of the vegetation growth rate along with the integration of the other facets of the investigation (gypsum production, pedology, climatology, and topography) indicates patterns of areas of reduced vegetation growth rate for each of the growth periods from 1946-70. This effect is attributed to the reduction of photosynthesis as a result of the coating of dust on the leaf canopy. The affected areas display a distinct pattern of distribution in relation to the emission source. The pattern appears to be a function of gypsum production, wind direction and speed, particle size, topography, and the installation of air pollution control devices. The analysis also revealed the effectiveness of the mechanical dust collectors which the gypsum plant installed to reduce the pollution emitted from the stack.

This study did not, and was not intended to, solve the problem of air pollution by industrial gypsum dust. This must be accomplished through the efforts of improved environmental education and technology. It is the hope of the author that this study will serve as a stimulus to more sophisticated and detailed studies of the problem of industrial dust in the environment, and that a contribution was made to the understanding and appreciation of the problem and to the advancement of the science of geography.

APPENDIX A

GYPSUM PRODUCTION VALUES

(Tons per Year)

YEAR	YEARLY PRODUCTION	AVERAGE	GROWTH PERIOD
1946	N/A		
1947	194,744		
1948	208,326	233,575	1946-50
1949	262,175		
1950	269,027		
1951	320,992		
1952	276,016		
1953	237,648	289,636	1951-55
1954	282,483		
1955	331,045		
1956	352,776		
1957	127,550		
1958	293,372	288,517	1956-60
1959	320,506		
1960	348,384		
1961	347,776		
1962	462,004		
1963	483,496	450,328	1961-65
1964	474,584		
1965	483,684		
1966	439,431		
1967	408,764		
1968	514,576	478,068	1966-70
1969	543,528		
1970	484,041		

Source: Department of Mines, Oklahoma City, Oklahoma.

APPENDIX B

SOIL TYPES AND CHARACTERISTICS

SOIL CHARACTERISTICS

Soil Type	Texture	Available Water Capacity	Reaction (pH)	Permeability	Soil Hydrological Group*
Br Broken Alluvial Land	--	--	--	--	B
CsA Carville-Shellabarger Complex	0-8" Fine Sandy Loam 8-32" Silty Clay Loam 32-50" Sandy Loam	.12 .14 .12	6.1-6.5 6.1-6.5 6.6-7.3	Slow	C
Bk Breaks-Alluvial Land Complex	--	--	--	--	C
Er Eroded Loam Sand	--	--	--	--	C
NcB NcC Nobscott Fine Sand	0-60" Fine Sand	.07	5.6-6.5	Moderately Rapid	A
PrB PrC Pratt Loamy Fine Sand	0-50" Loamy Fine Sand	.07	6.6-7.3	Moderately Rapid	A
Ro Rough Broken Land	--	--	--	--	D
RnC2 RcB Renfrow Silty Clay Loam	0-10" Silty Clay Loam 10-50" Clay	.17 .17	6.6-7.3 6.6-7.3	Very Slow Very Slow	D
Sb Sandy Broken Land	--	--	--	--	C
ShA ShC Shellabarger Fine Sandy Loam	0-12" Fine Sandy Loam 12-34" Silty Clay Loam 34-60" Silt Loam	.14 .14 .14	6.1-6.5 6.6-7.3 6.6-7.3	Moderate	B

Soil Type		Texture	Available Water Capacity	Reaction (pH)	Permeability	Soil Hydrological Group*
VaB	Vanoss Loam	0-16" Loam	.14	6.1-6.5	Moderate	B
		16-60" Clay Loam	.17	6.1-6.5		
VeB		0-8" Clay Loam	.17	7.4-7.8	Very Slow	D
Vr		8-17" Clay	.17	7.4-7.8		
VeC						

*Hydrologic Soil Group represents a group of soils that have similar rates of infiltration, and when wetted, similar rates of permeability, or transmission of water within the soil. Four Hydrologic groups are recognized.

A -- has a high infiltration, even when thoroughly wet. High rate of water transmission and low runoff potential. Deep, well drained to excessively drained, and consist chiefly of sand, gravel, or both.

B -- has moderate infiltration rate when thoroughly wet. Rate of water transmission and potential runoff is moderate. Moderately deep to deep, moderately well drained to well drained, and have fine to moderately course texture.

C -- has a slow infiltration rate when thoroughly wet. Rate of water transmission is slow, and runoff potential is high. These soils have a layer that impedes downward movement of water, or they are of moderately fine to fine texture and have a slow infiltration rate.

D -- has very slow infiltration rate when thoroughly wet. Rate of water transmission is very slow, and runoff potential is very high. Included in this group are (1) clay soils with a high shrink-swell potential; (2) soils with a permanently high water table; (3) soils with a claypan or clay layer at or near the surface; and (4) soils shallow over nearly impervious material.

Source: Fisher, Soil Survey of Blaine County, Oklahoma, 1968.

APPENDIX C

VEGETATION SAMPLES (cm)

X	Y	Sample no.	1946-50	1951-55	1956-60	1961-65	1966-70
1	1	1					
		2			no data		
		3					
		avg					
2	1	1	1.75	1.00	.80	1.00	.60
		2	1.10	1.35	1.45	1.30	1.00
		3	1.40	1.20	1.00	.95	1.10
		avg	1.41	1.18	1.08	1.08	.90
3	1	1	1.05	.90	.65	.70	.65
		2	.95	1.40	1.10	1.50	1.00
		3			no data		
		avg	1.00	1.15	.87	1.10	.82
4	1	1	--	--	1.90	1.70	1.60
		2	.95	1.35	1.30	1.60	1.10
		3	1.25	.90	1.10	1.80	1.20
		avg	1.10	1.12	1.43	1.70	1.30
5	1	1	.85	1.00	.70	1.20	1.20
		2	2.60	1.35	1.50	2.50	2.10
		3	1.00	.60	.60	.70	.65
		avg	1.48	.98	.93	1.46	1.31
6	1	1					
		2			no data		
		3					
		avg					
7	1	1					
		2			no data		
		3					
		avg					
8	1	1					
		2			no data		
		3					
		avg					
1	2	1	1.05	.65	1.30	1.00	1.30
		2	1.30	1.15	1.30	.95	1.30
		3			no data		
		avg	1.18	.90	1.30	.97	1.30

X	Y	Sample no.	1946-50	1951-55	1956-60	1961-65	1966-70
2	2	1	2.50	1.80	2.05	.80	1.25
		2	2.35	1.80	2.00	1.45	1.60
		3	1.00	.80	.90	.90	1.10
		avg	1.95	1.46	1.65	1.05	1.31
3	2	1	.45	.60	.60	.50	.50
		2	.95	.60	.75	.85	.80
		3	1.00	.65	.75	1.05	.65
		avg	.80	.61	.70	.80	.65
4	2	1	1.10	1.40	.50	1.20	.70
		2	1.00	.80	.95	.45	.50
		3	.95	.80	.70	.75	.55
		avg	1.01	1.00	.71	.80	.58
5	2	1	1.70	1.20	1.45	1.40	1.10
		2	1.80	1.00	.50	.80	.90
		3	1.20	1.00	.50	.80	.90
		avg	1.56	1.06	1.03	1.10	1.06
6	2	1					
		2			no data		
		3					
		avg					
7	2	1					
		2			no data		
		3					
		avg					
8	2	1					
		2			no data		
		3					
		avg					
1	3	1	1.10	.95	2.10	1.50	.90
		2	1.35	1.20	.90	1.95	1.60
		3			no data		
		avg	1.22	1.07	1.50	1.73	1.30
2	3	1			no data		
		2	.70	.60	.40	.65	.55
		3			no data		
		avg	.70	.60	.40	.65	.55

X	Y	Sample no.	1946-50	1951-55	1956-60	1961-65	1965-70
3	3	1	.40	.35	.50	.55	.40
		2	.65	.30	.55	.40	.25
		3	.60	.35	.50	.60	.55
		avg	.55	.33	.51	.51	.40
4	3	1	1.20	.80	.90	.85	1.10
		2	.95	.80	1.00	.90	.90
		3			no data		
		avg	1.07	.80	.95	.88	1.00
5	3	1	1.55	1.30	1.60	1.50	.90
		2	1.60	1.15	1.60	1.15	.90
		3			no data		
		avg	1.57	1.22	1.60	1.32	.90
6	3	1					
		2			no data		
		3					
		avg					
7	3	1					
		2			no data		
		3					
		avg					
8	3	1					
		2			no data		
		3					
		avg					
1	4	1	1.10	1.00	1.40	.90	.70
		2	.70	1.00	1.30	.80	.95
		3	1.90	.90	1.40	1.40	1.20
		avg	1.23	.96	1.36	1.03	.95
2	4	1	2.20	1.15	1.05	1.75	.80
		2	1.90	.85	1.00	1.15	.90
		3	2.35	1.10	.90	.95	.65
		avg	2.15	1.03	.98	1.28	.78
3	4	1	.55	.35	.25	.25	.45
		2	.70	.50	.70	.70	.55
		3	.30	.35	.30	.40	.30
		avg	.51	.40	.41	.45	.43

X	Y	Sample no.	1946-50	1951-55	1956-60	1961-65	1966-70
4	4	1	.75	.80	.85	.80	.70
		2	.80	1.30	1.20	1.00	.40
		3	1.00	1.20	.70	.60	.60
		avg	.85	1.10	.91	.80	.56
5	4	1	1.50	1.05	1.15	1.30	1.25
		2	1.00	.60	.65	.55	.70
		3	.85	.80	.55	.70	.65
		avg	1.11	.81	.78	.85	.86
6	4	1					
		2			no data		
		3					
		avg					
7	4	1	1.70	1.20	.80	1.60	1.40
		2			no data		
		3			no data		
		avg	1.70	1.20	.80	1.60	1.40
8	4	1	1.20	.80	.65	.90	.70
		2	.90	.85	.70	.70	.60
		3	1.30	.80	1.00	.90	.80
		avg	1.08	.73	.78	.83	.70
1	5	1	.95	.90	1.30	1.10	1.40
		2	1.45	1.00	1.55	1.40	1.40
		3	1.00	.90	1.00	1.30	1.20
		avg	1.13	.93	1.28	1.26	1.33
2	5	1					
		2			no data		
		3					
		avg					
3	5	1	1.00	.85	1.20	.95	1.15
		2	1.00	.55	.80	1.10	.65
		3	1.30	.85	.65	.60	.55
		avg	1.10	.75	.88	.88	.78
4	5	1	1.30	.70	1.00	.90	.80
		2	1.25	.70	.70	.75	.50
		3	.55	.65	.70	.70	.50
		avg	1.03	.68	.80	.78	.68

X	Y	Sample no.	1946-50	1951-55	1956-60	1961-65	1966-70
5	5	1	1.00	.55	.70	.90	.90
		2	1.00	.45	.40	.50	.50
		3	1.20	1.05	.40	1.60	.85
		avg	1.06	.68	.50	1.00	.75
6	5	1	1.35	1.25	1.35	1.30	1.00
		2			no data		
		3			no data		
		avg	1.35	1.25	1.35	1.30	1.00
7	5	1	.95	.80	1.05	1.60	1.55
		2			no data		
		3			no data		
		avg	.95	.80	1.05	1.60	1.55
8	5	1	1.65	.60	.65	.55	.70
		2			no data		
		3			no data		
		avg	1.65	.60	.65	.55	.70
1	6	1	1.15	1.15	1.15	1.45	1.15
		2	.85	.75	.50	.95	1.20
		3	1.35	1.30	1.15	.95	.60
		avg	1.11	1.06	.93	1.11	.98
2	6	1	--	--	1.50	1.50	2.10
		2	.80	.70	.80	1.00	.85
		3	.90	.75	.85	1.60	.90
		avg	.85	.72	1.05	1.36	1.28
3	6	1	1.80	1.70	1.25	1.70	1.25
		2	.60	.55	.40	.55	.40
		3	.90	.80	1.90	1.90	1.80
		avg	1.10	1.01	1.18	1.38	1.15
4	6	1	.80	.45	.60	.70	.50
		2	1.05	1.30	.85	1.80	1.45
		3	.40	.50	.40	.50	.65
		avg	.75	.75	.61	.60	.86
5	6	1	.40	.40	.70	1.10	1.85
		2	1.70	.80	1.10	1.70	1.35
		3	1.75	1.50	1.90	2.10	1.90
		avg	1.28	.90	1.23	1.63	1.70

X	Y	Sample no.	1946-50	1951-55	1956-60	1961-65	1966-70
6	6	1	.65	.95	1.20	1.20	.80
		2	4.20	1.85	2.20	2.90	2.10
		3	1.50	.70	.50	.80	.70
		avg	2.11	1.16	1.30	1.63	1.20
7	6	1	1.45	.90	.95	1.10	1.30
		2			no data		
		3			no data		
		avg	1.45	.90	.95	1.10	1.30
8	6	1	1.80	1.10	1.50	1.65	1.30
		2			no data		
		3			no data		
		avg	1.80	1.10	1.50	1.65	1.30
1	7	1	2.40	1.50	1.60	.90	.95
		2	.70	.50	.65	.80	1.75
		3	.90	.50	.45	.50	.45
		avg	1.33	.83	.90	.73	1.05
2	7	1	.80	.60	.80	.70	.80
		2	1.05	1.25	.70	1.10	.90
		3	1.20	.75	1.00	.85	.60
		avg	1.01	.86	.83	.88	.76
3	7	1	1.30	.85	1.10	1.10	.85
		2			no data		
		3			no data		
		avg	1.30	.85	1.10	1.10	.85
4	7	1	1.70	.65	1.20	.75	.50
		2	1.65	1.15	1.55	1.10	.95
		3	.80	.50	.75	.80	.75
		avg	1.38	.75	1.16	.88	.73
5	7	1			no data		
		2	.75	.50	.85	1.30	.80
		3			no data		
		avg	.75	.50	.85	1.30	.80
6	7	1					
		2			no data		
		3					
		avg					
7	7	1	1.30	1.10	.90	1.25	1.40
		2			no data		
		3			no data		
		avg	1.30	1.10	.90	1.25	1.40

X	Y	Sample no.	1946-50	1951-55	1956-60	1961-65	1966-70
8	7	1					
		2			no data		
		3					
		avg					
1	8	1					
		2			no data		
		3					
		avg					
2	8	1	.80	.70	1.25	.85	.70
		2	1.70	1.20	1.70	1.55	1.10
		3	.65	1.00	1.25	2.05	1.40
		avg	1.05	.96	1.40	1.48	1.06
3	8	1	2.10	1.50	1.50	1.40	1.05
		2			no data		
		3			no data		
		avg	2.10	1.50	1.50	1.40	1.05
4	8	1	.45	.50	.45	1.00	1.30
		2	1.25	1.10	1.50	1.70	1.60
		3			no data		
		avg	.85	.80	.97	1.35	1.45
5	8	1	.50	.55	.70	.75	.55
		2	1.90	1.20	.85	1.30	.80
		3	1.05	.75	.60	.90	.65
		avg	1.15	.83	.71	.98	.66
6	8	1	1.00	1.15	1.10	1.15	1.00
		2	.75	1.10	2.20	.90	.60
		3			no data		
		avg	.87	1.12	1.65	1.02	.80
7	8	1					
		2			no data		
		3					
		avg					
8	8	1					
		2			no data		
		3					
		avg					

APPENDIX D

CONTROL VEGETATION

Sample no.	1946-50	1951-55	1956-60	1961-65	1966-70
1	1.90	1.10	1.30	1.05	.75
2	1.25	1.10	2.25	1.30	.80
3	1.05	1.10	1.40	1.30	.80
4	1.10	1.10	1.60	1.05	1.10
5	1.90	1.30	1.30	1.00	1.00
6	.70	.80	1.05	1.20	1.00
7	1.25	1.55	1.10	1.10	.65
8	.80	.95	.80	.70	.60
9	2.70	2.00	1.75	1.65	1.30
10	1.50	1.40	1.20	1.15	1.25
11	1.20	1.15	1.30	1.25	1.00
12	.80	.80	.80	.65	.55
13	1.20	1.20	.90	.90	1.00
14	2.00	1.10	.75	.85	.80
15	--	2.20	1.80	1.60	1.45
16	1.50	1.70	1.30	1.25	.80
17	--	--	2.15	2.05	1.75
18	--	--	3.40	2.55	2.20
19	--	1.30	1.80	1.55	.70
20	1.00	.95	.95	1.20	.80
21	1.00	.60	.65	.55	.70
22	1.70	1.60	1.50	1.50	1.10
23	--	--	1.70	2.05	1.95

APPENDIX E

ANALYSIS OF VARIANCE TESTS FOR TREND SURFACE ANALYSES

1946-50

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Confidence Level %
Due to Linear	.27	2	.13	.86	50
Deviations from Linear	6.72	44	.15		
Due to Quadratic	.53	3	.17	1.13	50
Deviations from Quadratic	6.19	41	.15		
Due to Cubic	.18	4	.04	.25	5
Deviations from Cubic	6.01	37	.16		
Due to Quartic	.74	5	.14	.87	25
Deviations from Quartic	5.27	32	.16		
Due to Quintic	.95	6	.15	.93	50
Deviations from Quintic	4.32	26	.16		
Due to Sextic	.91	7	.13	.76	25
Deviations from Sextic	3.42	19	.17		
Total	6.98	46			

Source: Author's calculations.

1951-55

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Confidence Level %
Due to Linear	.02	2	.01	.16	25
Deviations from Linear	2.77	44	.06		
Due to Quadratic	.35	3	.11	2.20	75
Deviations from Quadratic	2.42	41	.05		
Due to Cubic	.25	4	.06	1.20	50
Deviations from Cubic	2.18	37	.05		
Due to Quartic	.40	5	.08	1.60	75
Deviations from Quartic	1,77	32	.05		
Due to Quintic	.44	6	.07	1.40	50
Deviations from Quintic	1.33	26	.05		
Due to Sextic	.25	7	.03	.60	25
Deviations from Sextic	1.08	19	.05		
Total	2.80	46			

Source: Author's calculations.

1956-60

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Confidence Level %
Due to Linear	.21	2	.10	.90	50
Deviations from Linear	5.20	44	.11		
Due to Quadratic	.31	3	.10	.90	50
Deviations from Quadratic	4.89	41	.11		
Due to Cubic	.22	4	.05	.41	25
Deviations from Cubic	4.67	37	.12		
Due to Quartic	.48	5	.09	.69	25
Deviations from Quartic	4.19	32	.13		
Due to Quintic	1.17	6	.19	1.72	75
Deviations from Quintic	3.02	26	.11		
Due to Sextic	.67	7	.09	.75	25
Deviations from Sextic	2.35	19	.12		
Total	5.41	44			

Source: Author's calculations.

1961-65

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Confidence Level %
Due to Linear	.15	2	.07	.63	25
Deviations from Linear	5.16	44	.11		
Due to Quadratic	.36	3	.12	1.09	50
Deviations from Quadratic	4.81	41	.11		
Due to Cubic	.78	4	.19	1.90	75
Deviations from Cubic	4.03	37	.10		
Due to Quartic	1.39	5	.27	3.37	97.5
Deviations from Quartic	2.64	32	.08		
Due to Quintic	.46	6	.07	.87	75
Deviations from Quintic	2.18	26	.08		
Due to Sextic	.70	7	.10	1.42	75
Deviations from Sextic	1.48	19	.07		
Total	5.32	46			

Source: Author's calculations.

1966-70

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Confidence Level %
Due to Linear	.10	2	.05	.50	25
Deviations from Linear	4.43	44	.10		
Due to Quadratic	.46	3	.15	1.66	75
Deviations from Quadratic	3.96	41	.09		
Due to cubic	1.01	4	.25	3.57	97.5
Deviations from Cubic	2.95	37	.07		
Due to Quartic	.80	5	.16	2.66	95
Deviations from Quartic	2.16	32	.06		
Due to Quintic	.32	6	.05	.71	25
Deviations from Quintic	1.84	26	.07		
Due to Sextic	.53	7	.07	1.16	75
Deviations from Sextic	1.30	19	.06		
Total	4.53	46			

Source: Author's calculations.

APPENDIX F

TREND SURFACE EQUATIONS

1946-50 Fifth Degree Equation

$$Z = -4.36634 + 8.60381\ X + 1.64133\ Y + -4.67218\ X^2 + -1.09530\ XY + -0.50475\ Y^2 + 1.03946\ X^3 + 0.55941\ X^2Y + -0.08000\ XY^2 + 0.14557\ Y^3 + -0.09795\ X^4 + -0.08657\ X^3Y + -0.02376\ X^2Y^2 + 0.03094\ XY^3 + -0.02219\ Y^4 + 0.00310\ X^5 + 0.00485\ X^4Y + 0.00125\ X^3Y^2 + 0.00047\ X^2Y^3 + -0.00200\ XY^4 + 0.00122\ Y^5$$

1951-55 Fourth Degree Equation

$$Z = 3.53502 + -1.00379\ X + -1.65938\ Y + 0.08830\ X^2 + 0.40535\ XY + 0.40528\ Y^2 + 0.02438\ X^3 + -0.05723\ X^2Y + -0.05206\ XY^2 + -0.04344\ Y^3 + -0.00430\ X^4 + 0.00822\ X^3Y + -0.00405\ X^2Y^2 + 0.00550\ XY^3 + 0.00135\ Y^4$$

1956-60 Fifth Degree Equation

$$Z = -14.00318 + 14.48533\ X + 8.83662\ Y + -5.52869\ X^2 + -5.47552\ XY + -2.41392\ Y^2 + 1.05929\ X^3 + 1.25963\ X^2Y + 0.82553\ XY^2 + 0.40603\ Y^3 + -0.10516\ X^4 + -0.09709\ X^3Y + -0.16001\ X^2Y^2 + -0.03192\ XY^3 + -0.04350\ Y^4 + 0.00398\ X^5 + 0.00327\ X^4Y + 0.00558\ X^3Y^2 + 0.00611\ X^2Y^3 + -0.00059\ XY^4\ 0.00202\ Y^5$$

1961-65 Fourth Degree Equation

$$Z = 1.52443 + 0.06455\ X + -0.14537\ Y + -0.08785\ X^2 + -0.32400\ XY + 0.14451\ Y^2 + 0.05994\ X^3 + -0.03141\ X^2Y + 0.09657\ XY^2 + -0.03713\ Y^3 + -0.00717\ X^4 + 0.00984\ X^3Y + -0.01000\ X^2Y^2 + -0.00157\ XY^3 + 0.00193\ Y^4$$

1966-70 Third Degree Equation

$$Z = 3.23755 + -1.18187\ X + 0.86781\ Y + 0.25771\ X^2 + 0.06956\ XY + 0.16828\ Y^2 + -0.01632\ X^3 + -0.00481\ X^2Y + -0.00376\ XY^2 + -0.01005\ Y^3$$

BIBLIOGRAPHY

BIBLIOGRAPHY

Ackerman, Phillip. Geography as a Fundamental Research Discipline. Chicago: University of Chicago Department of Georgraphy Research Paper, 1958.

Air Conservation. Washington, D.C.: Publication No. 80 of the American Association for the Advancement of Science, 1965.

Air Quality Criteria for Particulate Matter: Summary and Conclusions. Washington, D.C.: U.S. Department of Health, Education, and Welfare, Public Health Service. No date.

Bach, Wilfred. Atmospheric Pollution. New York: McGraw-Hill Book Company, 1972.

Broek, Jan O. M., and Webb, John W. Geography of Mankind. New York: McGraw-Hill Book Company, 1968.

Darley, Ellis F. "Studies on the Effect of Cement-Kiln Dust on Vegetation," Journal of the Air Pollution Control Association, 16 (3): 145-150, 1966.

Donahue, Roy L.; Schickluna, John C.; and Robertson, Lynn S. Soils: An Introduction to Soils and Plant Growth. New Jersey: Prentice-Hall, 1971.

Doraiswamy, Paul C. Energy Balance and Spectral Properties of a Reflectorized Soybean Canopy. Lincoln: University of Nebraska College of Agriculture, 1971.

Dubos, Rene. A God Within. New York: Charles Scriveners and Sons, 1972.

Ehrenfeld, David W. Biological Conservation. New York: Holt, Rinehart, and Winston, Inc., 1970.

Fisher, Carl F. Soil Survey of Blaine County, Oklahoma. Washington, D.C.: U.S. Department of Agriculture, Soil Conservation Service, 1968.

Fritts, Harold C. "Growth Rings of Trees," Science, 154 (3752): 973-979, 1966.

Gerard, C. J. Influence of Transpiration Suppresants, Sprinkler Irrigation and Moisture Levels on Transpiration and Evaporation. Bryan: Texas A and M University Water Resources Institute, 1970.

Good, Donald I. FORTRAN II Trend Surface Program for the IBM 1620. Lawrence: University of Kansas, Special Distribution Publication No. 14, State Geological Survey, 1964.

Gray, Fenton, and Galloway, H. M. Soils of Oklahoma. Stillwater: Oklahoma State University, 1959.

Hall, F. P., Jr., and Hagan, Richard R. A Preliminary Case Study of Long Distance Transport of Air Pollution. Norman: University of Oklahoma Department of Meteorology Special Publication, 1971.

Heimbach, James A. "The Correlation of Polluted Air with Tree Growth and Lung Disease in Humans," Journal of Computers in Biology and Medicine, 1:243-253, 1971.

Jameson, William Carl, and Schiel, Joseph B., Jr. "A Preliminary Investigation on the Relationship between Gypsum Dust and Vegetation Growth," Bios, 43(2):65-69, 1972.

Johnson, Forrest L., and Risser, Paul G. "Correlation Analysis of Rainfall and Annual Ring Index of Central Oklahoma Blackjack Oak and Post Oak," American Journal of Botany, 60(5):475-478, 1973.

Krause, Paul. Users Guide to Department of Geography Program Library and Other Computer Software. Norman: University of Oklahoma Department of Geography Technical Paper No. 1, 1974.

Krumbein, W. C., and Graybill, Franklin A. An Introduction to Statistical Models in Geology. New York: McGraw-Hill Book Company, 1965.

Leopold, Aldo. A Sand County Almanac. New York: Ballantine Books, 1966.

Lowry, William P. Weather and Life: An Introduction to Biometeorology. New York: Academic Press, 1967.

Newell, Reginald E. "The Global Circulation of Atmospheric Pollutants," Scientific American, 224(2):32-42, 1971.

Sheahan, J. S. "Effect of Gypsum Dust on the Environment," Minerals Processing (March 1971): 13-17.

Slade, David H. (ed.). Meteorology and Atomic Energy. Oak Ridge, Tennessee: U.S. Atomic Energy Commission, 1968.

The Sources of Air Pollution and Their Control. Washington, D.C.: Public Health Service Publication No. 1548, 1969.

Williams, James D., and Edmisten, Norman G. An Air Resource Management Plan for the Nashville Metropolitan Area. Cincinnati: Public Health Service, 1965.

PERSONAL CORRESPONDENCE

Baker, J. R., Works Manager, United States Gypsum Company Processing Plant, Southard, Oklahoma. 8-18-71.

Butterworth, Connie, Public Relations Assistant, United States Gypsum Company, Chicago, Illinois. 6-5-74.

Fleming, Bern, Jim Walter Corporation, Tampa, Florida. 6-3-74.

Fritts, Harold C., Professor of Dendrochronology, University of Arizona Laboratory of Tree-Ring Research, Tucson, Arizona. 2-10-72.

Satre, Mark S., Public Relations, Kaiser Cement and Gypsum Corporation, Oakland, California. 6-4-74.

The Gypsum Association, Chicago, Illinois, 6-13-74.